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## DE L'ACADÉMIE DES SCIENCES DE L'URSS

NOUVELLE SÉRIE

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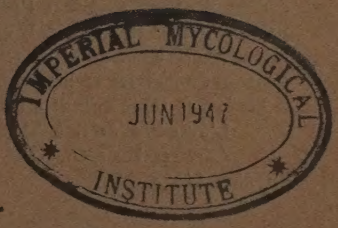


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*MATHEMATICS*

# ON THE DISTRIBUTION OF CHARACTERS

By U. V. LINNIK

*(Communicated by I. M. Vinogradow, Member of the Academy, 9.VIII.1943)*

Among the principal hypotheses of the theory of arithmetical characters, immediately connected with Riemann's extended hypothesis, there is a hypothesis on the uniform distribution of values of characters over the primes lying in the intervals with the length equal to a power of the modulus, *viz.*, $D$ being the modulus of the character, there is an absolute constant $K$ such that the quantities of primes on the segment $[1, D^{K'}]$, $K' \geqslant K$, with prescribed values of the character are asymptotically equal (we consider characters of bounded order).

Here I expose two theorems which cover the contents of this hypothesis to a considerable degree.

Theorem 1. *If $\chi$ is a complex character* (mod $D$), *then*

$$\sum_{p>2} \chi(p) \ln p e^{-p/N} \ll N\left(e^{-\frac{\ln N}{\ln D}} + \frac{1}{\ln D}\right). \tag{1}$$

Theorem 2. *Let $-D$ be a fundamental discriminant, $D>0$, $h(-D)=h$, the class number of $k(\sqrt{-D})$. Then*

$$\sum_{p>2} \left(\frac{-D}{p}\right) \ln p e^{-p/N} \ll N\left(e^{-\frac{\ln N}{\ln D}} + e^{-\frac{h}{\sqrt{D}} \ln N} + \frac{1}{\ln D}\right).$$

The demonstration of these theorems is based upon the expression of the sums (1) by means of Mellin's transforms through the poles of the function $-\frac{L'}{L}(s) = \sum \chi(n) \Lambda(n) n^{-s}$ $(\sigma > 1)$ as given by J. E. Littlewood in his remarkable paper «On the class-number of the corpus $P(\sqrt{-k})$» (1), and also upon the integration and the Féjer summation of Fourier series of almost periodic functions (2).

In view of the great length of the proof I will here only discuss a comparatively simple case relating to characters with $L$-series satisfying certain supplementary simplifying conditions. We consider the series $L(s) = \sum \chi(n) n^{-s}$ and we call the zeros lying in the half-plane $\sigma \geqslant 1 - \frac{2 \ln \ln D}{\ln D}$ essential zeros and the other ones — non-essential. We introduce now the following simplifying assumptions:

1°. For $|t| < (\ln \ln D)^2$ all essential zeros are situated on the vertical line $\sigma = \sigma_0$.

2°. The distance between the neighbouring zeros is $> A/\ln D$.

3°. Among all unit segments of our interval the segment $|t| \leqslant 1/2$ contains the maximum quantity of zeros $M$.

4°. $L(0) \neq 0$.

In this case making use of certain well-known properties of $L$-series (3), Mellin's transforms and $\Gamma$-functions, we shall find, proceeding according to Littlewood, that

$$S(\chi, \delta) = \sum_{n=1}^{\infty} \chi(n) \Lambda(n) e^{-\delta n} = \sum_{k} \delta^{-\rho_k} \Gamma(\rho_k) + O(\ln D)$$

where the summation is to be extended over all zeros of $L(s)$ in the critical strip. Separating the essential zeros $\rho_k = \sigma_0 + it_k$, we shall obtain:

$$S(\chi, \delta) = \delta^{-\sigma_0} \sum_{k} \delta^{-it_k} \Gamma(\rho_k) + O(\ln D) + O(\delta^{-1} e^{\frac{2 \ln \ln D}{\ln D} \ln \delta} \ln D).$$

We denote $-\ln \delta = x$ and consider the almost periodic function $\psi(x) = \sum \Gamma(\rho_k) e^{it_k x}$.

Let us prove the existence of constants $B_1$ and $B_2 > 1$ such that there is a $x_0 \in [B_1 \ln D, B_2 \ln D]$ with $|\psi(x_0)| > M^{1/3}$ ($M$ is the zero quantity of p. 3°).

Then, as we shall see, the quantity $M$ must necessarily be small, and this enables to prove (1).

We introduce the auxiliary function

$$g(x) = \sum_{|t_k| \leqslant 1/2} \overline{\Gamma(\rho_k)} e^{-i\left(t_k + \frac{C_0}{\ln D}\right)x}$$

where $C_0 < A/2$ is a constant whose value will be fixed afterwards.

Denoting now $x_1 = \ln D$, we obtain

$$\Phi(x) = \int_{x_1}^{x} dx \int_{x_1}^{x} \psi(x)\, g(x)\, dx = f(x) + P(x)$$

where

$$f(x) = -\sum_{|t_k| \leqslant 1/2} \sum_{j} \overline{\Gamma(\rho_k)} \Gamma(\rho_j) \frac{e^{i\left(t_j - t_k - \frac{C_0}{\ln D}\right)x}}{\left(t_k - t_j + \frac{C_0}{\ln D}\right)^2}$$

$$P(x) = A_1 x + A_2 = A_1 (x - \alpha).$$

If $C_0$ is sufficiently small with respect to $A$, then for $x = x_2 = 2 \ln D$ we obtain: $|f(x_2)| > c_1 M \ln^2 D$.

Let us consider two distinct cases:

1. $|P(x_2)| > 1/2 c_1 M \ln^2 D$.

It is then easy to show that there are $B_1$ and $B_2 > 1$ such that

$$\left| \int_{B_1 \ln D}^{B_2 \ln D} P(x)\, dx \right| > 10 c_1 M \ln^3 D$$

and

$$\left| \int_{B_1 \ln D}^{B_2 \ln D} f(x)\, dx \right| < 5 c_1 M \ln^3 D.$$

Hence, using Schwarz' inequality and taking into account that

$$\left| \int_{B_1 \ln D}^{B_2 \ln D} |g(x)|^2 \, dx \right| < c_3 M \ln M \ln D$$

we can easily verify our lemma.

2. $|P(x)| \leqslant {}^1/_2 c_1 M \ln^2 D$.

Then

$$|\Phi(x)| \geqslant {}^1/_2 c_1 M \ln^2 D$$

and the lemma is verified in the same way.

Thus, for a certain $\delta_1 = e^{-x_0}$ we have

$$|S(\chi, \delta_1)| > \delta_1^{-\sigma_0} M^{1/3} + O(\delta_1^{-1}/\ln D).$$

But it is evident that

$$|S(\chi, \delta_1)| < \sum_{n=1}^{\infty} \Lambda(n) e^{-\delta_1 n} \sim \Gamma(1) \delta_1^{-1} = \delta_1^{-1}.$$

From this we deduce immediately:

$$\delta_1^{-\sigma_0} M^{1/3} < 2\delta_1^{-1}, \text{ so that } M < \cdot \delta_1^{3(\sigma_0 - 1)}.$$

Hence for $\delta < \delta_1$

$$S(\chi, \delta) \ll \delta^{-\sigma_0} \delta_1^{3(\sigma_0 - 1)} + \delta^{-1}/\ln D \ll \delta^{-1} \left(\frac{\delta}{\delta_1^3}\right)^{1-\sigma_0} + \delta^{-1}/\ln D.$$

If $\delta < \delta_1^4$, this quantity is less than $\delta^{-1}\left(\delta^{\frac{1-\sigma_0}{4}} + \frac{1}{\ln D}\right)$. As it is known with regard to complex characters that $\sigma_0 < 1 - \frac{c_4}{\ln D}$, we have proved (1).

A detailed proof will soon be published in the «Recueil Mathématique».

Addendum. The further development of this method, the principal difficulty of which consists in the avoiding the supposition 2°, p. 2, has led me to the theorem that the least prime in an arithmetic progression $Dx + l$, $(l, D) = 1$, is $\ll \exp(A \ln D \ln\ln\ln D)$.

The method can perhaps be applied to the segments $[1, D^K]$, in this case too.

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9.VIII.1943.

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*MATHEMATICS*

# ON CERTAIN SUMS OCCURRING IN THE ANALYTIC THEORY OF NUMBERS

By N. TCHUDAKOFF

*(Communicated by I. M. Vinogradow, Member of the Academy, 28.IX.1943)*

In the present note the author indicates a new method of investigation of certain sums playing an important rôle in the analytic theory of numbers. This method is exposed in application to a particular example of Vinogradow-Goldbach's theorem, and hence its exposition is closely connected to one of the previous papers of the author (1).

Denotations. $n$ is a natural number $\geqslant 1$; $M$, an arbitrarily given positive number; $a$ and $q$, two natural numbers satisfying the conditions: $a < q$, $(a, q) = 1$, $q \leqslant (\lg n)^M$; $\rho = e^{2\pi i \frac{a}{q}}$; $\chi_0(m)$, principal character mod $q$; $S_n = \sum_{m \leqslant n} \chi_0(m) \Lambda(m) \rho^m$, where $\Lambda(m)$ is Mangoldt's function; $c_1$, $c_2$, ... are quantities depending only on $M$.

Lemma.

$$S_n = \frac{\mu(q)}{\varphi(q)} n + O\left(n e^{-c_1 \sqrt{\lg n}}\right),$$

*where $\mu(q)$ is Möbius' function and $\varphi(q)$, Euler's function.*

Proof. Consider the Dirichlet series

$$f(s) = \sum_{m=1}^{\infty} \frac{\chi_0(m) \Lambda(m) \rho^m}{m^s}. \tag{1}$$

The coefficients of this series evidently satisfy the conditions of the well-known theorem of Landau (2). The application of this theorem to the series (1) yields the equality

$$S_n = \frac{1}{2\pi i} \int_{a-iT}^{a+iT} \frac{n^s f(s)\, ds}{s} + O\left(n e^{-\sqrt{\lg n}} \lg^3 n\right) \tag{2}$$

where $a = 1 + (\lg n)^{-1}$; $T = e^{\sqrt{\lg n}}$.

It is further known (3) that

$$\rho^m \chi_0(m) = \frac{1}{\varphi(q)} \sum_{a'=1}^{q} \rho^{a'} \sum_{(\chi)} \chi(m) \bar{\chi}(a').$$

Substituting this expression for $\rho^m \chi_0(m)$ in the right-hand side of the equality (1), we find

$$\frac{1}{2\pi i} \int_{a-iT}^{a+iT} \frac{n^s f(s)}{s} ds = \frac{-1}{\varphi(q)} \sum_{(\chi)} \sum_{a'=1}^{q} \rho^{a'} \bar{\chi}(a') \frac{1}{2\pi i} \int_{a-iT}^{a+iT} \frac{n^s}{s} \frac{L'}{L}(s, \chi)\, ds. \tag{3}$$

Consider now the set of zeros of the function $L(s, \chi)$ for all moduli $q' \leqslant q$; in virtue of the known result of Page (4), all these zeros with the possible exception of one «exceptional» real zero $\beta$ are situated outside the domain

$$\sigma \geqslant 1 - \frac{c_2}{\lg q(|t|+2)}, \quad -\infty < t < +\infty. \tag{4}$$

Furthermore, if this «exceptional» zero $\beta$ exists, then by Siegel's theorem (5) it satisfies the inequality

$$\beta \leqslant 1 - c_3 q^{-\varepsilon}$$

where $\varepsilon$ is an arbitrary positive number.

Finally, it may be established by classical methods that in the domain (4) we have the estimations

$$-\frac{L'}{L}(s, \chi) - \frac{1}{s-1} = O(\lg^3 q(|t|+2))$$

if $\chi = \chi_0$, *i. e.* $\chi$ is the principal character;

$$-\frac{L'}{L}(s, \chi) + \frac{1}{s-\beta} = O(\lg^3 q(|t|+2))$$

if $L(\beta, \chi) = 0$;

$$-\frac{L'}{L}(s, \chi) = O(\lg^3 q(|t|+2))$$

if $L(\beta, \chi) \neq 0$ and $\chi$ is not the principal character.

We introduce now an auxiliary quantity $\delta(T)$ defined as follows

$$\delta(T) = \begin{cases} \eta/3, & \text{if } 1-\eta \leqslant \beta \leqslant 1 - {}^2/_3\eta \\ \eta, & \text{if } \beta > 1 - {}^2/_3\eta \end{cases}$$

where $\eta = \frac{c_2}{\lg q(T+2)}$.

Then for any character $\chi(m)$ we have on the polygon with the vertices $(a-Ti,\ 1-\delta(T)-iT,\ 1-\delta(T)+iT,\ a+Ti)$ the estimation

$$-\frac{L'}{L}(s, \chi) = O(\lg^3 qT).$$

Hence, applying the classical theorem of Cauchy to every integral on the right-hand side of (3), we obtain:

$$-\frac{1}{2\pi i}\int_{a-iT}^{a+iT}\frac{n^s}{s}\frac{L'}{L}(s,\chi)\,ds = nE(\chi)-\frac{n^\beta}{\beta}\tilde{E}(\chi)-$$

$$-\frac{1}{2\pi i}\int_{a-iT}^{1-\delta(T)-iT}\frac{n^s}{s}\frac{L'}{L}(s,\chi)\,ds-\frac{1}{2\pi i}\int_{1-\delta(T)-iT}^{1-\delta(T)+iT}\frac{n^s}{s}\frac{L'}{L}(s,\chi)\,ds-$$

$$-\frac{1}{2\pi i}\int_{1-\delta(T)+iT}^{a+iT}\frac{n^s}{s}\frac{L'}{L}(s,\chi)\,ds = nE(\chi)-\frac{n^\beta}{\beta}\tilde{E}(\chi)+$$

$$+O\left(\frac{n}{T}\lg^3 qT\right)+O\left(n^{1-\delta(T)}\lg^3 qT\int_0^T\frac{dt}{\sqrt{t^2+\frac{1}{4}}}\right)=$$

$$=nE(\chi)-\frac{n^\beta}{\beta}\tilde{E}(\chi)+O\left(ne^{-c_8\sqrt{\lg n}}\right)+O\left(n^{1-\delta(T)}\lg^2 n\right)$$

where

$$E(\chi)=\begin{cases}1, & \text{if } \chi=\chi_0, \text{ i. e. } \chi \text{ is the principal character,}\\ 0, & \text{if } \chi\neq\chi_0.\end{cases}$$

$$\tilde{E}(\chi)=\begin{cases}1, & \text{if } L(\beta,\chi)=0\\ 0, & \text{if } L(\beta,\chi)\neq 0.\end{cases}$$

But

$$n^{1-\delta(T)}\leqslant n^{1-\eta/3}=O\left(ne^{-c_8\sqrt{\lg n}}\right).$$

Put, further, in Siegel's inequality $\varepsilon=1/2M$; then we shall have

$$\frac{n^\beta}{\beta}\tilde{E}(\chi)=O\left(n^\beta\right)=O\left(n^{1-c_9(\lg n)^{-1/2}}\right).$$

Thus we find

$$-\frac{1}{2\pi i}\int_{a-iT}^{a+iT}\frac{n^s}{s}\frac{L'}{L}(s,\chi)\,ds=nE(\chi)+O\left(ne^{-c_8\sqrt{\lg n}}\right).$$

Replace now every integral on the right-hand side of equality (3) by its expression given by the last formula; then we obtain

$$\frac{1}{2\pi i}\int_{a-iT}^{a+iT}\frac{n^s f(s)}{s}\,ds=\frac{n}{\varphi(q)}\sum_{a'=1}^{q}\rho^{a'}\chi_0(a')+$$

$$+O\left(\varphi(q)\,ne^{-c_8\sqrt{\lg n}}\right)=\frac{n}{\varphi(q)}\sum_{(a',q)=1}\rho^{a'}+$$

$$+O\left(ne^{-c_7\sqrt{\lg n}}\right)=\frac{\mu(q)}{\varphi(q)}\,n+O\left(ne^{-c_7\sqrt{\lg n}}\right).$$

Comparing this equality with the equality (2), we finally obtain:

$$S_n=\frac{\mu(q)}{\varphi(q)}\,n+O\left(ne^{-c_1\sqrt{\lg n}}\right).$$

Theorem. *Let the function $\psi(x)$ be differentiable for all values of $x \geqslant n_0$; then holds the equality*

$$\sum_{m=n_0}^{n} \chi_0(m)\lambda(m)\rho^m\psi(m) = \frac{\mu(q)}{\varphi(q)} \sum_{m=n_0}^{n} \psi(m) +$$

$$+ O\left(ne^{-c_1\sqrt{\lg n}}\left(\sum_{m=n_0}^{n} |\psi'(m+\vartheta)| + |\psi(n+1)| + 1\right)\right)$$

*where $\vartheta$ denotes a quantity $\leqslant 1$ by modulus.*

Proof. Put $S_n = \frac{\mu(q)}{\varphi(q)} n + \Delta(n)$, $n = 1, 2, 3 \ldots$, then, obviously,

$$\sum_{m=n_0}^{n} \chi_0(m)\lambda(m)\rho^m\psi(m) = \sum_{m=n_0}^{n} (S_m - S_{m-1})\psi(m) =$$

$$= \frac{\mu(q)}{\varphi(q)} \sum_{m=n_0}^{n} \psi(m) + \sum_{m=n_0}^{n} (\Delta(m) - \Delta(m-1))\psi(m) =$$

$$= \frac{\mu(q)}{\varphi(q)} \sum_{m=n_0}^{n} \psi(m) - \psi(n_0)\Delta(n_0 - 1) + \sum_{m=n_0}^{n} \Delta(m)(\psi(m) - \psi(m+1)) +$$

$$+ \psi(n+1)\Delta(n).$$

But in virtue of the lemma proved above we have the estimation

$$\Delta(m) \leqslant c_8 m e^{-c_1\sqrt{\lg m}} \leqslant c_8 n e^{-c_1\sqrt{\lg n}}$$

Consequently

$$\left| \sum_{m=n_0}^{n} \Delta(m)(\psi(m) - \psi(m+1)) + \psi(n+1)\Delta(n) \right| \leqslant$$

$$\leqslant c_8 n e^{-c_1\sqrt{\lg n}}\left(\sum_{m=n_0}^{n} |\psi'(n+\vartheta)| + |\psi(n+1)|\right)$$

which proves our theorem, as may be easily seen.

On ground of the just proved theorem it is not difficult to establish the validity of the fundamental lemma 10 of my paper (1). In fact, preserving all conditions of this lemma, we may, be using elementary estimations, easily establish the equality

$$S(\alpha) = \sum_{s \leqslant p \leqslant n} e(p\alpha) = \sum_{m=3}^{n} \frac{\lambda(m)\chi_0(m)e^{2\pi i\left(\frac{a}{q}+\vartheta\right)m}}{\lg m} + O(\sqrt{n})$$

Putting now $\psi(x) = e^{2\pi i\vartheta x}(\lg x)^{-1}$, and using the theorem proved above, we obtain

$$S(\alpha) = \frac{\mu(q)}{\varphi(q)} \sum_{m=3}^{n} \frac{e^{2\pi i\vartheta m}}{\lg m} + O\left(ne^{-c_1\sqrt{\lg n}}\left(\sum_{m=3}^{n} \frac{2\pi|\vartheta|}{\lg m} + \frac{1}{m\lg^2 m}\right)\right) =$$

$$= \psi_{aq}(\alpha) + O\left(ne^{-c_1\sqrt{\lg n}}\frac{n|\vartheta|}{\lg n}\right) = \psi_{aq}(\alpha) + O(ne^{-c_1\sqrt{\lg n}}\xi^{5/3}) =$$

$$= \psi_{aq}(\alpha) + O(ne^{-c_9\sqrt{\lg n}})$$

which proves lemma 10.

In a similar way may be found the principal part of the sum of the form

$$\sum_{m \leqslant n} \lambda(m)\, a_m$$

where $a_m$ is a linear function of a finite number of characters to different (or equal) fixed moduli, or, more generally, a linear function of a finite number of totally multiplicative functions.

In particular, investigating the sum

$$\frac{1}{\varphi(q)} \sum_{m \leqslant n} \lambda(m) \sum_{\chi} \overline{\chi}(a)\, \chi(m)$$

we obtain, as is known, an estimation of the difference

$$\pi(n, q, a) - \frac{1}{\varphi(q)} \int_2^n \frac{dx}{\lg x}.$$

Different questions of the theory of distribution of primes lead to sums of the indicated form.

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*PHYSICS*

# DEPOLARIZATION OF PHOTOLUMINESCENCE ON DECAYING

By S. I. WAWILOW, Member of the Academy

In accordance with the generally adopted views on the process of photoluminescence in liquid and solid media, one may in certain cases expect a gradual depolarization to take place on the decaying of the emission. This phenomenon does not appear to have engaged any one's attention so far, in spite of its considerable importance as a new means of determining the basic features of the processes developing in the medium. To instance this may serve the «decay depolarization» of the emission of certain uranyl glasses, discovered by A. N. Sevchenko[1]*.

Behind the depolarization observed on decaying one should surmise the operation of two principal causes: 1) The Brownian rotation of excited molecules if the viscosity of the medium is such as to permit an appreciable rotation to be made during the mean lifetime of the excited state. 2) The resonance between the excited and unexcited molecules.

To these two causes primarily responsible for depolarization may add a third, of rather incidental character, connected with overlapping of absorption and emission spectra. Strictly speaking, such overlapping, whenever it occurs, cannot but affect the law of decay[2]; the radiation will be protracted because of the repeated acts of absorption and emission, and a weakening of polarization will take place. Moreover, the repeated absorptions will be by molecules that have noticeably changed their orientation if the viscosity of the medium is not too high.

A concrete quantitative computation of the depolarization effect is hardly possible in this case. Yet, it is certain that a slight intersection between the absorption and emission spectra cannot account alone for a strong depolarization.

This case will not be entered into here, and the computations will be based on the two principal depolarizing factors mentioned above.

## § 1. «Decay Depolarization» as Due to Brownian Rotation of Molecules

The hypothesis of Brownian rotation of molecules as a factor in the depolarization of photoluminescence has been developed into a theory by Lewschin [3] and Perrin [4], and this theory is almost directly applicable to the solution of our problem. For that purpose we can make use of the relations derived by Perrin [4].

Suppose, to begin with, that the excitation is practically instantaneous (compared to the rate of decay) and is effected by a beam of light directed

* In crystals (of uranyl salts, for instance) «decay depolarization» may fail to appear owing to the uniform orientation of the molecules.

along the $y$-axis; that the electric oscillations in the exciting polarized light are directed along the $z$-axis and that the $x$-axis is given by the direction of observation. Denote by $L_{x_0}$, $L_{y_0}$, $L_{z_0}$ the energies pertaining respectively to three non-coherent linear dipole oscillations, corresponding to the instant of excitation $t=0$. On the theory of Brownian rotation we find for $L_{x_0}=0$ that

$$L_{yt}=\frac{1}{3\tau}e^{-\frac{t}{\tau}}\left[(1+2e^{-6ft})L_{y_0}+(1-e^{-6ft})L_{z_0}\right]dt$$

$$L_{zt}=\frac{1}{3\tau}e^{-\frac{t}{\tau}}\left[(1+2e^{-6ft})L_{z_0}+(1-e^{-6ft})L_{y_0}\right]dt.$$

From this we obtain the following formula for the degree of polarization as a function of time

$$P_1=\frac{L_{zt}-L_{yt}}{L_{zt}+L_{yt}}=\left[\frac{L_{z_0}-L_{y_0}}{L_{z_0}+L_{y_0}}\right]\frac{3e^{-6ft}}{2+e^{-6ft}}=P_0\frac{3e^{-6ft}}{2+e^{-6ft}} \tag{1}$$

where

$$f=\frac{1}{6}\frac{RT}{v\eta} \tag{2}$$

$R$ is the gas constant; $T$, absolute temperature; $v$, molecular volume of a dissolved molecule with the solvent's particles sticking to it; $\eta$, viscosity.

If the excitation instead of occurring instantaneously takes a practically infinite length of time, the depolarization should obey a law different from (1). Let us consider this case. Denoting by $t_1$ the time of observation, measured from the beginning of excitation, by $\theta$ the current time of excitation, and by $\theta_0$ the time when the excitation expires, $t_1-\theta_0=t$, we have

$$L_y(t)=\frac{1}{3\tau}\left[L_{y_0}\int_0^{\theta_0}e^{-\frac{(t_1-\theta)}{\tau}}(1+2e^{-6f(t_1-\theta)})\,d\theta+\right.$$

$$\left.+L_{z_0}\int_0^{\theta_0}e^{-\frac{(t_1-\theta)}{\tau}}(1-e^{-6f(t_1-\theta)})\,d\theta\right]dt$$

$$L_z(t)=\frac{1}{3\tau}\left[L_{z_0}\int_0^{\theta_0}e^{-\frac{(t_1\theta-)}{\tau}}(1+2e^{-6f(t_1-\theta)})\,d\theta+\right.$$

$$\left.+L_{y_0}\int_0^{\theta_0}e^{-\frac{(t_1-\theta)}{\tau}}(1-e^{-6f(t_1-\theta)})\,d\theta\right]dt.$$

Hence

$$P_2(t)=P_0\frac{3e^{-6ft}}{2(1+6f\tau)+e^{-6ft}}. \tag{3}$$

## § 2. «Decay Depolarization» as Due to Resonance

Proceeding on the general theory in which the effect of concentration on the fluorescence in solutions is explained in terms of the resonance relationship between excited and unexcited molecules (6), we arrive at the following expressions for the probability that there will be no transfer of energy to neighbouring particles during time $t$ at concentration $c$

$$q(c,\ t)=e^{-\lambda_0 c}\cdot e^{-\frac{ct}{k_2}} \tag{4}$$

$$w(c,\ t)=e^{-\omega_0 c}\cdot e^{-\frac{ct}{k_1}} \tag{5}$$

$q(c, t)$ and $w(c, t)$ corresponding respectively to transfers without and with quenching. In these formulae $\lambda_0$, $\omega_0$, $k_1$, $k_2$ are constants.

Denote by $p_0$, $p_1$, $p_2$, $p_3$, ... the degrees of polarization of a group of molecules radiating respectively with such a number of transfers of excitation energy to neighbouring molecules as is indicated by the subscripts 0, 1, 2, 3, *etc.*

There is no doubt (5) that

$$p_0 > p_1 > p_2 > p_3 > \cdots \tag{6}$$

We shall in the first place discuss the case of a practically instantaneous excitation. The polarization measured at the time when the interval $t$ has elapsed since the excitation is

$$P(t) = \frac{\sum p_i I_i(t)}{\sum I_i(t)} \tag{7}$$

where $I_i$ is the intensity of the light emitted in a given direction, corresponding to the $i$-th link. Because of the anisotropy of a polarized radiation (6)

$$I_i(t) = \frac{2}{3 - p_i} s_i \tag{8}$$

where $s_i$ is the probability of re-emission after $i$ transfers have been effected.

The probability of radiation without transfer and quenching, $s_0$, is expressed, in virtue of (4) and (5) and because of the spontaneous character of the emission during the interval from $t$ to $t+dt$, by the product

$$s_0 = e^{-\omega_0 c} \cdot e^{-\frac{ct}{k_1}} \cdot e^{-\lambda_0 c} \cdot e^{-\frac{ct}{k_2}} \cdot \frac{1}{\tau} e^{-\frac{t}{\tau}} dt. \tag{9}$$

According to (4) and (5) the probabilities $q$ and $w$ remain below unity when $t = 0$. For this reason the probability of radiation after one transfer is expressed by a sum of two terms

$$s_1 = s_1' + s_1'' \tag{10}$$

where $s_1'$ corresponds to a transfer after some time $\theta$, and $s_1''$ to an instantaneous transfer.

The probability $s_1'$ is expressed by an integral of the product of the following probabilities (the limits of integrations are from 0 to $t$):

1) That a molecule excited at the instant $t = 0$ will not be quenched during the interval $\theta$, *i. e.* $e^{-\omega_0 c} \cdot e^{-\frac{c\theta}{k_1}}$.

2) That a molecule excited at a time comprised between $\theta$ to $\theta + d\theta$ will not be quenched during the period extending from $\theta$ to $t$, *i. e.* $e^{-\omega_0 c} \cdot e^{-\frac{c(t-\theta)}{k_1}}$.

3) That a transfer of excitation energy will take place between $\theta$ and $\theta + d\theta$, *i. e.* $e^{-\lambda_0 c} \frac{c}{k_2} e^{-\frac{c\theta}{k_2}} d\theta$.

4) That there will be no transfer of energy during $t - \theta$, *i. e.* $e^{-\lambda_0 c} e^{-\frac{(t-\theta)c}{k_2}}$.

5) That re-emission will occur between $t$ and $t+dt$, *i. e.*, $\frac{1}{\tau} e^{-\frac{t}{\tau}} dt$.

$$s_1' = \int_0^t e^{-c(\omega_0+\lambda_0)c} e^{-t\left\{\frac{1}{\tau}+\frac{c}{k_1}+\frac{c}{k_2}\right\}} \frac{c}{k_2 \tau} d\theta\, dt = \frac{c}{k_2 \tau} e^{-c(\omega_0+\lambda_0)} e^{-t\left\{\frac{1}{\tau}+\frac{c}{k_1}+\frac{c}{k_2}\right\}} t\, dt. \tag{11}$$

On the other hand, the probability $s_1'$ is expressed by the product of the probabilities:

1) That there will be no instantaneous quenching $e^{-\omega_0 c}$.

2) That no quenching will occur at a second place within the time from 0 to $t$, *i. e.* $e^{-\omega_0 c} e^{-\frac{ct}{k_1}}$.

3) That there will be instantaneous transfer $(1-e^{-\lambda_0 c})$.

4) That there will be no second transfer during the period from 0 to $t$, *i. e.* $e^{-\lambda_0 c} e^{-\frac{ct}{k_2}}$.

5) That re-emission will occur at an instant comprised between $t$ and $t+dt$, *i. e.* $\frac{1}{\tau} e^{-\frac{t}{\tau}} dt$.

$$s_1' = \frac{1}{\tau} e^{-2c(\omega_0+\lambda_0)} (1-e^{-\lambda_0 c}) e^{\lambda_0 c} e^{-t\left\{\frac{1}{\tau}+\frac{c}{k_1}+\frac{c}{k_2}\right\}} dt. \tag{12}$$

From (11) and (12) we have in virtue of (10)

$$s_1 = \frac{e^{-2c(\omega_0+\lambda_0)}}{\tau} e^{-t\left\{\frac{1}{\tau}+\frac{c}{k_1}+\frac{c}{k_2}\right\}} \left[\frac{c}{k_2} t + e^{\lambda_0 c} - 1\right] dt. \tag{13}$$

Applying a similar reasoning to $s_2$, $s_3$, *etc.*, we find

$$s_n = \sum_{i=0}^{i=n} \frac{n!}{[(n-i)!]^2 i!} \left(\frac{ct}{k_2}\right)^{n-1} \frac{1}{\tau} (1-e^{-\lambda_0 c})^i e^{i\lambda_0 c} \times$$

$$\times e^{-(n+1)c(\omega_0+\lambda_0)} e^{-t\left\{\frac{1}{\tau}+\frac{c}{k_1}+\frac{c}{k_2}\right\}} dt. \tag{14}$$

Substitution of (8) and (14) into (7) gives a formula, that is rather cumbersome in the full form. Taking (6) into consideration, we confine ourselves in this paper to the first two terms of the sums in (7), assuming moreover that $\frac{2}{3-p_i}$ in (7) differs but little from $^2/_3$. With these simplifications we find

$$P_1(t) \approx \frac{p_0 + p_1 e^{-c(\omega_0+\lambda_0)} \left[\frac{c}{k_2} t + e^{\lambda_0 c} - 1\right]}{1 + e^{-c(\omega_0+\lambda_0)} \left[\frac{c}{k_2} t + e^{\lambda_0 c} - 1\right]}. \tag{15}$$

After transformation we have

$$P_1(t) \approx p_0 - (p_0 - p_1) \frac{e^{-c(\omega_0+\lambda_0)} \left[\frac{c}{k_2} t + e^{\lambda_0 c} - 1\right]}{1 + e^{-c(\omega_0+\lambda_0)} \left[\frac{c}{k_2} t + e^{\lambda_0 c} - 1\right]}. \tag{16}$$

It is seen from (16) that if $t$ is small, $P$ decreases linearly with time; then the depolarization is slowed down tending for $t=\infty$ to $p_i$. Without the adopted simplifications the polarization would, of course, have zero for limit.

Taking into account the simplifications made in deriving (16), it may be remarked that (16) faithfully describes the run of the depolarization observed by Sevchenko [1] on the decay of emission in uranyl glasses. For a complete experimental verification of the theory set forth here the values of the constants $\omega_0$, $\lambda_0$ and $k_2$ should be obtained independently; they may be computed from the data on the variation of the yield and duration of the emission as functions of the concentrations.

If should be noted that just as in the case where Brownian rotation is the responsible cause, the law of the decay polarization arising from resonance is subject to a certain modification upon the transition from instantaneous to prolonged excitation. Omitting here the simple intermediate computation, we pass at once to the statement that with an excitation extended over a practically infinite interval of time, the decay should (under the same simplifying assumptions) proceed according to the formula

$$P_2(t) \approx p_0 - (p_0 - p_1) \frac{e^{-c(\omega_0+\lambda_0)}\left[\frac{c}{k_2}t + \frac{\frac{c}{k_2}}{\left(\frac{c}{k_1}+\frac{c}{k_2}+\frac{1}{\tau}\right)} + e^{\lambda_0 c} - 1\right]}{1 + e^{-c(\omega_0+\lambda_0)}\left[\frac{c}{k_2}t + \frac{\frac{c}{k_2}}{\left(\frac{c}{k_1}+\frac{c}{k_2}+\frac{1}{\tau}\right)} + e^{\lambda_0 c} - 1\right]}. \qquad (17)$$

The available phosphoroscopes and fluorometers permit the decay polarization to be measured within the widest possible range of duration of an emission.

As is seen from the computations referred to here, the depolarization curves open the possibility for a new method to be used in determining the constants, characterizing the Brownian rotation and the migration of the excitation energy through resonance in a fluorescent medium. It may as well be pointed out that if any noticeable rotation of molecules in a fluorescent medium, such as uranyl glass, for instance, is precluded by the conditions of viscosity and there is only a slight overlapping of absorption and emission spectra, then the weakening of polarization on the decay of emission is unmistakable evidence that a migration of the excitation energy takes place in the medium.

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*PHYSICS*

# POLARIZATION OF PHOTOLUMINESCENCE IN URANYL GLASSES

By A. N. SEVCHENKO

*(Communicated by S. I. Wawilow, Member of the Academy, 2.II.1944)*

Numerous attempts have been made to detect polarization in the luminescence emitted by uranyl salts in solutions and glasses but no definite results have been obtained.

Literary data on this subject are conflicting. Most of the experimenters ([1],[2]) have reported failures, but some, Perrin ([3]), for instance, claim to have observed a polarization of about 7—10 per cent in the emission of uranyl glass.

On studying the emission of uranyl glasses of different chemical composition I was able to establish that: 1) the polarization depends upon the chemical composition of the glass, and 2) varies sharply with the wave-length of the exciting light. Moreover, the study of a decaying emission in uranyl glasses has proved that 3) the degree of polarization falls off with the progress of the decay.

§ 1. Boric, boro-silicate and phosphate uranyl glasses have been investigated. Their chemical composition is given in Table 1.*

Table 1

| No. of glass | Molecular composition | Per cent composition of the charge |
|---|---|---|
| 6 | $K_2O \cdot 9B_2O_3$ | $K_2O$ (12.9%); $B_2O_3$ (86%); $UO_3$ (1%) |
| 3 | $Na_2O_2 \cdot 3B_2O_3$ | $Na_2O$ (12.95%); $B_2O_3$ (86%); $UO_2$ (1%) |
| 31 | $K_2O \cdot 7B_2O_3 \cdot 10SiO_2$ | $K_2O$ (7.9%); $B_2O_3$ (40.8%); $SiO_2$ (50.3%); $UO_2$ (1%); $Fe_2O_3$ (0.025%) |
| 1 | $K_2O \cdot 0.03Al_2O_3 \cdot 9B_2O_3 \cdot 10SiO_2$ | $SiO_2$ (77%); $B_2O_3$ (39%); $K_2O$ (10%); $Al_2O_3$ (3%); $UO_2$ (1%) |
| 15 | $Na_2O \cdot 3SiO_2$ | $Na_2O$ (25.4%); $SiO_2$ (73.6%); $UO_3$ (1%) |
| 35 | $BaO \cdot P_2O_5$ | BaO (51.5%); $P_2O_5$ (47.5%); $UO_2$ (1%) |

§ 2. It has been brought to light by these experiments that one of the reasons why the former attempts to detect a polarization of luminescence in uranyl glasses should have met with no success is that the quartz mercury lamp was used as the source of excitation, and the latter was practically effected by the mercury line 3650 Å of this lamp. Now, it is known that the polarization of luminescence, in general, may show a very sharp and peculiar dependence on the wave-length of the exciting light([4]), and I have found in my experiments that in the case of uranyl glasses this dependence is especially striking. It has just turned out that the exci-

* The glasses were prepared by T. I. Weinberg and I wish here to acknowledge my gratitude to her for having supplied the samples.

tation by $\lambda = 3\,650$ Å corresponds to the least degree of polarization of luminescence in uranyl glasses of different chemical composition.

The source of excitation in my experiments was a high voltage spark between nickel electrodes. Its light was passed through a double quartz Kipp monochromator.

The exciting light was polarized by an Iceland spar crystal, and one of the polarized components of the light beam was screened.

For quantitative estimations of the degree of polarization as affected by excitation with different wave-lengths, I made use of Savar's polarimeter with glass-pile ([5]).

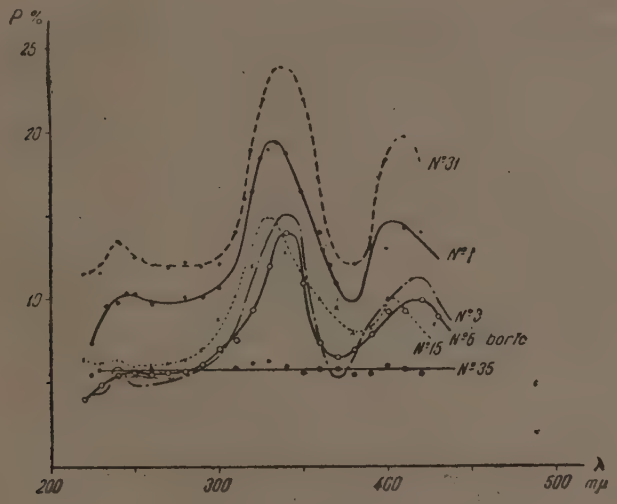


Fig. 1

In measuring slight degrees of polarization an additional set of glass plates was placed at a certain angle to polarize the light of luminescence. The exciting light passing through the glass under investigation was excluded by means of crossed light filters.

The results of these estimations are represented graphically in Fig. 1.

As is seen from the run of the curves, the polarization spectra of boric (Nos. 6 and 3), boro-silicate (Nos. 1 and 31) and alkaline-silicate (No. 15) glasses show a characteristic relation to the wave-length of the exciting light.

A remarkable fact with the phosphate glass (No. 35) is that it is not in the least selective in this respect. The polarization curves of boric (Nos. 6 and 3) and boro-silicate glasses (Nos. 31 and 1) have three quite similar maxima relating to different wave-lengths. The first lies in the region of 400 to 420 mμ, the second corresponds to the range of 330—340 mμ, and the third to that of 240—250 mμ. Throughout the run of the curves the absolute values of polarization for boric glasses have turned out to be nearly equal. Though the polarization spectra of the two boro-silicate glasses exhibit a general likeness of structure, yet the absolute values of polarization are throughout the course of the curve much higher for the glass No. 31 than for glass No. 1.

In this connexion it may be mentioned that No. 31 contains slight quantities of iron which is known to be a quencher of fluorescence (see §1). Somewhat peculiar is the structure of maxima for the polarization spectrum of alkaline-silicate glass No. 15. It has only two maxima, both displaced by 10 mμ toward the short-wave side of the spectrum.

So in face of a general similarity of the polarization spectra in uranyl glasses of different composition, they also show certain individual features which can be made a subject of discussion.

§3. It is known in respect to organic dye solutions that the polarization of their fluorescence in many cases depends very strongly on their concentration, decreasing as the latter grows (6). It is, further, a well established fact that this effect of the concentration is a result of the quantum-mechanical resonance between excited and unexcited molecules (7). In order to find out the processes connected with the discovered polarization in uranyl glasses, it was only natural to follow up the variation of the polarization, yield and duration of the emission as functions of the concentration.

The polarization of the luminescence was measured in a series of boro-silicate glass samples, all of which had the same chemical composition.

The concentration of uranium varied from $4\times10^{-6}$ to $1\times10^{-2}$ g/cm$^3$. For excitation the long-wave ultra-violet light of a high-pressure quartz mercury tube was used.

The results of the measurement are listed in Table 2, from which it may be inferred that within a wide range of concentration ($2\times10^{-3}$ to $4\times10^{-6}$ g/cm$^3$) the content of uranium in the glass does not affect the limit polarization of luminescence.

Only at the transition to as high concentrations as $4\times10^{-3}$ to $1\times10^{-2}$ g/cm$^3$ does a slight decrease of polarization (about 3 per cent) take place. But even then it is too insignificant to infer from it any definite conclusions about the depolarization effect. In order to obtain a final solution of this problem, glasses containing more uranium have to be studied experimentally for the dependence of polarization on concentration.

Table 2

| $c$ g/cm$^3$ | $P$ % | $c$ | $P$ | $c$ | $P$ | $c$ | $P$ |
|---|---|---|---|---|---|---|---|
| $1\times10^{-3}$ | 10.4 | $1\times10^{-3}$ | 12.9 | $1\times10^{-4}$ | 12.8 | $1\times10^{-5}$ | 13.2 |
| $4\times10^{-3}$ | 11.2 | $4\times10^{-4}$ | 12.8 | $4\times10^{-5}$ | 12.9 | $4\times10^{-6}$ | 13.0 |
| $2\times10^{-3}$ | 12.7 | $2\times10^{-4}$ | 13.2 | $2\times10^{-5}$ | 12.6 | | |

The investigation of quenching by concentration carried out by S. I. Wawilow and W. L. Lewschin(2) has shown that in solutions of uranium salts the effect sets in at much higher concentrations than in solutions of organic dyes.

As is known from a number of papers (8), the effect of concentration depolarization is linked up with the shortening of the lifetime of the excited state in molecules. I have made phosphoroscopic measurements of the law of decay on a set of boro-silicate glass samples containing uranium in the following concentrations: $2\times10^{-5}$, $4\times10^{-5}$, $2\times10^{-3}$ and $4\times10^{-3}$ g/cm$^3$.

I found the decay in all cases to follow an exponential law. The value of $\tau$ for these concentrations is respectively $4.1\times10^{-4}$, $4\times10^{-4}$, $3.9\times10^{-4}$ and $3.65\times10^{-4}$ sec.

It will be obvious that with concentration ranging from $2\times10^{-3}$ to $2\times10^{-5}$ g/cm$^3$ the value of $\tau$ is practically constant. So is also the yield of luminescence which is equal to 43 per cent in this case. As the concentration is increased beyond the above-mentioned range, the yield tends to diminish and falls down to 35 per cent for $c=4\times10^{-3}$ g/cm$^3$.

If the results reported here be considered in the light of the hypothesis that the quantum-mechanical resonance underlies the effect of concentration on the properties of fluorescence in uranyl glasses, we may state that in this case the resonance between the excited and unexcited molecules is much less than in the case of dyestuff molecules, and this explains why the concentration had to obtain a high value before its effect became apparent.

§ 4. As early as 1923 Wawilow and Lewschin (⁸) had established by experiment that the luminescence of organic dyes is a radiation of dipole character. This conclusion was later confirmed by numerous studies theoretical as well as experimental.

Until now the nature of elementary radiators of photoluminescence in uranium compounds has remained obscure. From the absence of polarization in solutions of uranyl salts and glasses and from the long duration ($10^{-3}$—$10^{-4}$ sec.) of the excited state in the uranium molecule, as compared to organic compounds, one was led to think of quadrupole radiation in the case of these substances. At present the polarization of emission in uranyl glasses has made it possible to settle this question.

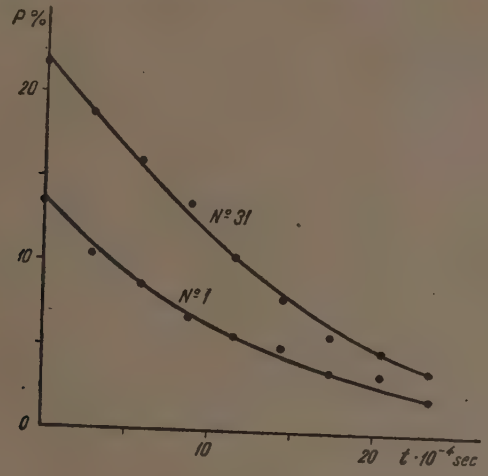


Fig. 2

S. I. Wawilow (⁹) has shown theoretically that the polarization of photoluminescence is a most sensitive and convenient method for determining the nature of elementary radiators. I have studied the polarization in uranyl glass with reference to the direction of observation and the position of the exciting electric vector; these data I have compared with similar data for fluorescein whose elementary nature of radiation is known. In this way I have established the dipole nature of the radiation of uranyl glasses. The limiting polarization of the investigated glass sample, as measured by means of Savar's polarimeter, turned out to equal 12.5 per cent. In view of this I selected a glycerine aqueous solution of fluorescein of such a viscosity that its limit polarization was also 12.5 per cent.

The measurements of the polarization in the fluorescein solution and in uranyl glass were so carried on that the angle of the exciting vector (beam) with the direction of observation was all the time equal to 90°.

Under these conditions the polarization curves for fluorescein and for uranyl glass showed a practically complete coincidence. This will mean that the luminescence of uranyl glass is a dipole radiation.

§ 5. On theoretical conceptions about the interaction between the excited and unexcited molecules in a solution and on the interpretation of the polarization effect in terms of the Brownian rotation of molecules we may naturally expect that the polarization of the luminescence should decrease as the latter is in progress of decaying (¹⁰). In order to verify this assumption phosphoroscopic experiments were started in which the degree of polarization in uranyl glasses was measured at different stage of decay.

The results of these measurements for two samples of uranyl glass are presented in Fig. 2. On the axis of abscissae is marked off the time of decay in seconds, and the ordinates give the measured polarization of luminescence in per cent.

The upper curve refers to boro-silicate glass No. 31; the lower curve, to glass No. 1. The course of these curves brings out a sharp dependence of the polarization on the time of decay. The observed degree of polarization declines steadily both in glass No. 31 and in glass No. 1. The absolute values of these polarization curves are different because of the difference in the limiting values.

In the case under consideration the depolarization of luminescence at different stages of decay cannot possibly be referred to Brownian movement, since the viscosity of the glasses is much too high. The most probable cause of the depolarization here is the migration of energy due to quantum-mechanical resonance between molecules.

In conclusion I wish to express my deep gratitude to S. I. Wawilow for his constant interest in this work and valuble suggestions.

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*PHYSICS*

# INTERFERENCE PHENOMENA IN THE CASE OF CHERENKOV RADIATION

By I. M. FRANK

*(Communicated by S. I. Wawilow, Member of the Academy, 27.XI.1943)*

As has been shown by S. I. Wawilow(1), the elementary nature of a radiator can be determined from the observation of interference phenomena. If in a luminous volume the distribution in angle of the radiators is isotropic, the observed angular distribution of intensity is, as a rule, uniform, and the polarization is equal to zero. Nothing can therefore be learned from these properties about the nature of the radiator. As for the interference visibility of strongly divergent rays, it proves in this case too to take different values, according as the radiation is of a dipole or quadrupole kind. Similar conclusions have been arrived at by Halpern and Doermann (2).

The radiation discovered in 1934 by Cherenkov(3) is of essentially different nature from the usual sources of light. The radiator here are electrons moving in a liquid at a speed higher than the phase velocity of light (4,5). Now, in relation to Cherenkov's radiation the question of interference phenomena has never been studied in detail.

This type of radiation is known to be one of pronouncedly directional character. Practically the entire energy of the radiation is concentrated in a very thin conic layer, and the angle formed by the cone's generatrix with the axis is $\theta_0$ ($\cos\theta_0 = 1/\beta n$; where $n$ is the refractive index of the medium and $\beta = v/c$ is the ratio of the electron velocity to that of light). From this it may be inferred that the cases where the radiation of an electron will proceed at once in two directions forming a given angle with each other, are likely to happen very rarely even if that angle is not above $2\theta_0$. It was supposed therefore that the interference visibility of Cherenkov's radiation must be very low in the case of divergent rays, and if the angle between the rays is above $2\theta_0$, no interference would take place at all (1). This contention is based, as will be shown later, on the erroneous assumption that the Cherenkov radiation remains sharply directional when the radiating volume is small in comparison with the wave-length of light.

The component of the field frequency $\omega$ of a uniformly moving electron is exactly imitated by the field of a continuous set of immovable harmonic oscillators, located on the trajectory of the electron and orientated in the direction of its velocity. Within any interval of the electron path $dl$ one may ascribe to these oscillators the electric moment (6)

$$p = \frac{\varepsilon}{\pi\omega} \sin\omega(t-\tau)\, dl \qquad (1)$$

where $\varepsilon$ is the charge of the electron, $t$, time; $\tau$, instant at which the electron is passing the point under consideration. The field of the electron is obtained by adding

up the fields of all such oscillators involved within a length $l$ equal to the path of the electron in the liquid. We shall find on performing this summation that at the point of observation as far away from the electron as at a distance $R \gg l$ the amplitude of the component of the field of frequency $\omega = \frac{2\pi c}{n\lambda}$ is (5)

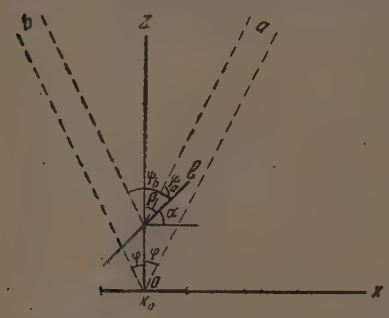
$$A = A_0 \frac{\sin\theta}{R} \frac{\sin\left\{\frac{\pi}{\beta n}\frac{l}{\lambda}(1-\beta n\cos\theta)\right\}}{(1-\beta n\cos\theta)} \qquad (2)$$

where $\theta$ is the angle between the ray drawn to the point of observation and the direction of electron's velocity. The phase coincides with the phase of the wave from oscillator located midway in the path of the electron.

In the subsequent only those velocities of the electron will be considered which exceed the phase velocity of ligth, *i. e.*

$$\beta n > 1 \qquad (3)$$

which is a necessary condition for Cherenkov's radiation to arise. Furthermore it will be supposed that the total path of the electron is considerably larger than the dimensions of the light source, *i. e.* that the length of $l$ is always equal to the extension of the light source in that direction.




From formula (2) it may be seen that if $l \ll \lambda/2$, the field is identical with that of a point dipole orientated in the direction of the electron velocity. Hence in the case of a small luminous volume, as compared to $\lambda/2$, the radiation of Cherenkov is undistinguishable from ordinary dipole radiation. For $l$ comparable to $\lambda/2$ or larger than $\lambda/2$, a typical directivity of the radiation becomes apparent. It is therefore only in this case, especially if one has to deal with widely divergent rays, that a reduction of the interference visibility for the Cherenkov radiation, as compared to ordinary sources of light, may be anticipated. Experiments made a few years ago by M. N. Alentzev (unpublished) lent no confirmation to this conclusion. What is more, it was shown by Alentzev for the simplest case that directivity does not preclude the observation of interference in Cherenkov's radiation, if conditons are created under which interference is observed in ordinary dipole radiation.

It will be seen later that the extension of the light source in the case of Cherenkov's radiation may lower the interference visibility not only more but sometimes less rapidly than with ordinary radiators, according to our choice of the direction of electron motion.

Denote by $a$ and $b$ the directions of the interfering rays from a light source having its centre at point $O$ (see figure). Let this point be considered as the origin of a rectangular system of coordinates. For the plane $xz$ of this system take the plane in which lie the rays $a$ and $b$, and direct the axis $z$ along the bisector of the angle formed by these rays, which we take to equal $2\varphi$.

Let us consider the interference of light from elementary non-coherent radiators distributed uniformly in the segment $l$ of a straight line bounded on two sides by planes parallel to the plane $yz$; *viz.* by the plane $x = -\frac{1}{2}$ and $x = +\frac{1}{2}x_0$. It is easy to see that the optical difference between the paths of rays parallel to $a$ and $b$ respectively is determined for any radiator by its coordinate $x$ alone, and varies directly as $2x\sin\varphi$. Let the distance between the planes by which the length of the luminous segment is bounded, be equal to

$$x_0 = \frac{\lambda}{2k \sin \varphi} \qquad (4)$$

where $k$ is an arbitrary coefficient.

Then $\lambda/k$ is the maximum change in the path difference of rays for the radiators placed on the opposite ends of the luminous segment. For $k \gg 1$ the interference visibility is a maximum, it diminishes with $k$ to become zero for the first time when $k = 1$.

This relation to $k$ evidently holds for any luminous segment bounded by these planes, whatever its position and orientation. The same relation of the interference visibility to $k$ is obtained if the whole volume between the planes is uniformly filled with radiators, *i. e.* when there is a plane-parallel luminous layer of thickness

$$x_0 = \frac{\lambda}{2k \sin \varphi}.$$

Things are different if we have Cherenkov's radiation for the source of light Suppose that the same segment $l$ coincides with the path of an electron that moves in a liquid and gives rise to the Cherenkov radiation. If $\alpha$ be the angle between the direction of its motion and $x$-axis, the path travelled by the electron will be

$$l = \frac{x_0}{\cos \alpha} = \frac{\lambda}{2k \sin \varphi \cos \alpha}. \qquad (5)$$

In this case the source of radiation may, as has been pointed out above, be considered to be located in the middle of the electron path. Therefore the path difference of the rays $a$ and $b$ will be such as if a point source were placed at the origin $O$.

The limits to the extension of the light source are in that case set solely by the fact that the directivity of the radiation increases with increasing $x_0$, and, accordingly, for certain $l$ the radiation is no longer observed simultaneously in the directions $a$ and $b$.

For an $l$ large enough formula (2) gives the maximum value of the amplitude at an angle $\theta_0$ determined from the condition

$$\cos \theta_0 = 1/\beta n. \qquad (6)$$

The amplitude goes down to zero as the angle is either increased from $\theta_0$ to $\theta_2$ or decreased from $\theta_0$ to $\theta_1$. Taking for $l$ its value from (5) we find by means of formula (2) that

$$\cos \theta_2 = \frac{1}{\beta n} - 2k \sin \varphi \cos \alpha \qquad (7)$$

$$\cos \theta_1 = \frac{1}{\beta n} + 2k \sin \varphi \cos \alpha. \qquad (8)$$

Let the angles between the directions of the electron motion and the rays $a$ and $b$ equal $\psi_a$ and $\psi_b$, respectively; then

$$\cos \psi_a = \sin \varphi \cos \alpha + \cos \varphi \cos \beta \qquad (9)$$

$$\cos \psi_b = -\sin \varphi \cos \alpha + \cos \varphi \cos \beta \qquad (10)$$

where $\beta$ is the angle formed by the electron velocity vector with the axis $x$.

It may be positively stated that interference will be observed at any rate if $\psi_a$ and $\psi_b$ fall within the range of the principal maximum of radiation, *i. e.*

$$\cos \theta_2 < \cos \psi_a < \cos \theta_1 \qquad (11)$$

$$\cos \theta_2 < \cos \psi_b < \cos \theta_1. \qquad (12)$$

One may easily convince himself that the inequalities (11) and (12) can both be satisfied simultaneously not only with $k \gg 1$ but also with $k = 1$, though for an ordinary source of light interference disappears when $k = 1$. Let us so choose, indeed, the direction of the electron velocity that $\psi_a$ be confined between $\theta_0$ and $\theta_1$, *i. e.*

$$\frac{1}{\beta n} < \sin \varphi \cos \alpha + \cos \varphi \cos \beta < \frac{1}{\beta n} + 2 \sin \varphi \cos \alpha.$$

Upon subtracting from all members of this inequality $2 \sin \varphi \cos \alpha$, we find that $\psi_b$ lies in this case between $\theta_0$ and $\theta_2$, being thus also confined to the range of the main maximum. It will be apparent that in the radiation of these electrons the interference visibility does not vanish even for $k=1$. The case is reverse if the direction of the electron motion is so chosen that for $k=1$ we have $\psi_a$ lying between $\theta_0$ and $\theta_2$. Then $\psi_b$ will be easily found to lie within the first collateral maximum in which the amplitude [see Formula (2)] has a negative sign. So in the case of these electrons the interference visibility becomes zero when $k$ is still larger than one. It appears therefore that in the case of Cherenkov's radiation the relation between the interference visibility and the extension of the light source is, generally speaking, different from what it is in the ordinary case, and depends upon the direction of the electron motion.

This difference is only natural. The radiation of Cherenkov has much in common with a non self-luminous source of light. It arises in fact from the summation of the field of mutually coherent dipole radiators.

A picture similar to that presented by Cherenkov's radiation is obtained (if we pay no attention to the orientation of the dipoles) upon the illumination of an infinitely thin slit by an obliquely falling beam of parallel rays (6). To choose the direction of the electron means in the case of a non self-luminous source to assign a definite direction to the illuminating beam of light. It is well known that in this case a non self-luminous source is not equivalent to a self-luminous source. From the same point of view it may be expected that for a Cherenkov radiation distributed isotropically over the angles, the interference visibility will very closely approach the state of affairs in an ordinary dipole radiation. It may here be remarked that the angular distribution of the Cherenkov radiation is determined not merely by the distribution in angle of the directions of the moving electrons but also by the shape of the light source. Suppose, *e. g.*, that the distribution in angle is isotropic and that again the electron paths are bounded by two parallel planes. If the distance $x_0$ between the planes is small compared to $\lambda$, then the electrons moving parallel to the $x$-axis radiate practically as a dipole. On the other hand, the electrons travelling at an angle to $x$-axis that is near to $\pi/2$, traverse large paths and for them all radiation is directed practically at an angle $\theta_0$ to the velocity. We thus see that although the intensity in the directions $a$ and $b$ is here equal, its angular distribution is not isotropic. If one begins to bound the path length and set to it a maximum value $l=L$, the angular distribution will become more isotropic. At the same time all mid-points of the electron paths will not lie in the $yz$ plane, and it will appear, moreover, that the directivity of radiation for these electrons is reduced.

Evidently, the interference properties of the Cherenkov radiation will thereby be brought nearer to the case of an ordinary light source. If $L$ is much less than $x_0$, the relationship between the interference visibility and the thickness of the layer must be identical with that for non-coherent radiators.

It is known that two radiators that are not self-luminous afford a means to obtain two coherent light sources, which circumstance is generally made use of in the observations of interference. A similar phenomenon should take place in the case of Cherenkov's radiation. By letting a beam of electrons pass through two small volumes of a liquid we obtain two self-luminous radiators which we may expect to be coherent.

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*BIOCHEMISTRY*

# CATALYSTS OF ACTIVITY OF ISOLATED CHLOROPLASTS

By E. A. BOYCHENKO

*(Communicated by A. A. Richter, Member of the Academy, 18.IX.1943)*

On the example of bacterial photosynthesis v. Niel demonstrated in 1930 that different donators of hydrogen are required for the photosynthetic reduction of carbon dioxide, which are to be chosen according to a given organism. According to v. Niel, in the case of reduction of carbon dioxide at the expense of hydrogen from some donator, one can also choose for the green plants an adequate substance with a definite redox potential, and to carry out photosynthesis independently of the living cell (1).

Later on a large number of inorganic and organic substances have been found that proved able to serve as donators of hydrogen in bacterial photosynthesis. As to the green plants, reduction was supposed to proceed in them at the expense of the water hydrogen, by way of special catalysts. No evidence of this was, however, available.

By the end of the thirties Gaffron succeeded in demonstrating that in green plants the reduction of carbon dioxide in the light may well proceed at the expense of the molecular hydrogen. The hydrogen is, however, no unique reducer, and may be substituted by an «internal donator of hydrogen», such as, for example, the glucose(2).

Somewhat later, Gaffron and Rubin have found that in an atmosphere of nitrogen green vegetable cells themselves are able to liberate hydrogen in the dark, the amount of the gas increasing tenfold in the case of illumination.

After Gaffron and Rubin, as a source of hydrogen serves one of the numerous reserve substances of the cell. In exhausted cells that have for a long time been breathing in darkness, the liberation of hydrogen is going on less intensely. It proceeds best of all directly after many hours of photosynthesis. Out of the various organic substances added to the cell-suspension, only glucose was found to act as a donator of hydrogen (3).

As under the conditions of these experiments the quantity of oxygen was very small as compared to that of glucose, the reduction of carbon dioxide might possibly have taken place at the expense of a partial oxidation of the glucose, without evolution of $CO_2$. Such partly oxidized carbohydrates seem to be able to serve as hydrogen acceptors (4).

Experiments with isolated chloroplasts go well to confirm the important part played in photosynthesis by reducing sugars. In none of the experimental sets, except those in which fructose was present, the solutions being with low water content and a rH below 5, the reduction of carbon dioxide in the light took place (5).

It was of interest to compare various reducing carbohydrates which are likely to serve as donators of hydrogen in the course of photosynthesis of green plants.

The comparison was carried out in the present work on films with isolated chloroplasts of white clover. Fresh clover leaves were cut with scissors in a 0.5 *M* galactose solution in tap water, at a ratio of 1 $cm^3$ of solution per 1 g of leaves. The extract was filtered through plankton silk, and the chloroplasts contained in it collected on a paper filter on a Büchner funnel by means of suction with a water-jet pump. The chlorophyl grains contained in 1 $cm^3$ of the extract were accumulated on 1 $cm^2$ of the filter and were dried on the funnel by means of suction.

For comparison were taken: maltose, glucose, fructose, glycol aldehyde and hydrosulphite as an inorganic reducer. The glycol aldehyde has been especially prepared for this purpose according to Fenton. A low rH that is indispensable for the reduction of carbon dioxide in the light may be rapidly obtained under conditions that coincide with the enolyzation of sugars. These conditions have been specified by Kusin, particularly in so far as they approach to biochemical ones ([6]).

It is on the ground of those works that for this experiment the saturated solution of basic magnesium acetate was chosen, as a medium whose pH and other properties approach most closely to the physical-chemical conditions of the cell. The solution was prepared according to Kusin, with addition of 0.1 per cent of carbon dioxide and of the films with the chloroplasts. The test-tubes-eudyometers were exposed to bright sunlight. The results of the comparison are summarized in the table below.

Catalysts of Activity of Isolated Chloroplasts

| Catalysts | Previous to experement | | Evolution of $O_2$ | After experiment | |
|---|---|---|---|---|---|
| | rH | pH | | pH | rH |
| Without catalyst | >14.4 | 8.0 | Abs. | 8.0 | >14.4 |
| Maltose 0.1% | <14.4 | 8.0 | Abs. | 8.0 | <9.9 |
| Glucose 0.1% | 9.9 | 8.0 | Slight | 8.3 | 5.2 |
| Fructose 0.1 % | <9.9 | 8.0 | Intense | 8.5 | <5.2 |
| Glycol aldehyde 0.1% | 5.2 | 8.0 | Abs. | 7.5 | >14.4 |
| Hydrosulphite 0.1% | <5.2 | 8.0 | Abs. | 8.0 | <5.2 |

Variation of pH was evaluated with Clarke's indicators, those of rH, according to the scale of redox indicators, dichlorphenolindophenol (22.4), methylene blue (14.4), indigo carmin (9.9), janusgreen (5.2). The shift of the pH towards alkalinity was found to coincide with the absorption of carbon dioxide, while the evolution of oxygen was recorded after a secondary oxidation of the leucodyes in the upper part of the test-tubes.

With no reducer, the rH of the solution being above 14, there were no traces whatever of reduction of carbon dioxide by the chloroplasts.

Upon addition of maltose the rH was somewhat abased, though no reduction took place.

In the glucose sets, both absorption of carbon dioxide and evolution of oxygen could be observed, though at a low degree.

Sets with fructose yielded better results. In spite of the oxidation of the leucodyes in the upper part of the test-tubes, a strong decrease of rH in the light was recorded. A similar drop of the rH in the case of illumination was also observed in the experiments with glucose and maltose, but then it was not so pronounced.

At the start of the experiment glycol aldehyde had a lower rH than the fructose. Nevertheless, it was oxidized very rapidly under bright illumination, and the solution entirely lost its reducing ability.

Under experimental conditions, hydrosulphite preserved a low rH, but it proved also unable to reduce carbon dioxide. This should be taken to mean that it is not only the rH that matters here, but the chemical nature of the reducer as well. In the case of green plants active forms of reducing sugars are being used instead of sulphuric compounds.

When choosing among the sugars, importance should be attached to the rapid drop of the rH of the solution below 5 (fructose, partly glucose, but no maltose), as well as to the integrity of the reducing ability (no glycol aldehyde should therefore be chosen, although it abases the rH more rapidly than fructose does).

As the reducing ability of a sugar solution rises when illuminated together with the chloroplasts, it may nevertheless be assumed that the fructose itself liberates no hydrogen, being not oxidized fully along with the reduction of carbon dioxide. More strictly speaking, it becomes rapidly active again upon the surface of the illuminated chloroplasts. Thus, the reduction of carbon dioxide will ultimately take place at the expense of the water hydrogen, yet of that used in no direct way but by means of sugar as a catalyst.

The experiments here described give ground to consider the active forms of reducing sugars to be those very catalysts of the photosynthesis of green plants which were being sought for since the first papers by v. Niel, and which under various denotation are present in all modern schemes of photosynthesis.

The author's thanks are due to Prof. A. P. Vinogradov, in whose laboratory the present investigation was carried out.

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*CYTOLOGY*

# ZYMONUCLEIC ACID OF THE PROTOZOIC CELL

By G. I. ROSKIN and A. S. GINSBURG

*(Communicated by L. A. Orbeli, Member of the Academy, 24.XII.1943)*

Foelgen's reaction made it possible to analyse on a wide scale and in detail the distribution and content variation of the zymonucleic acid (resp. chromatine) in various cells at different stages of their life-cycle. Quite different is the state of affairs with the yeast cell, or the cytoplasmic nucleic acid, concerning which in cytology and histophysiology nothing except some conjectures and indirect data

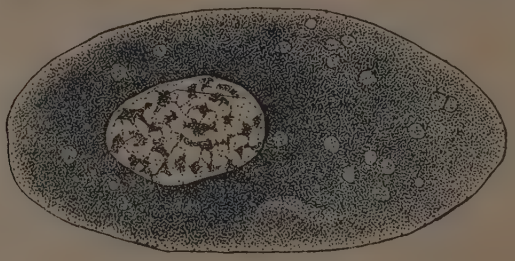

Fig. 1

are available. And as to the presence and distribution of the zymonucleic acid in *Protozoa*, literature seems to lack any observational data whatever.

In order to detect nucleic acid in the plasm we decided to made use of a method based on the studies by Dubos and McLeod (2), and by Brachet (1). This method is essentially based upon a comparison of two preparations, one of which was preliminarily treated by the enzyme ribonuclease which dissolves the nucleic acid of the plasm. As an object for our investigation we chose *Paramoecium caudatum*.

To obtain ribonuclease the following procedure was applied: a fresh beef pancreas was exposed to air during five or six hours; then, upon being thoroughly ground, it was added one and a half volume of 0.1 *N* acetic acid, and placed for 24 hours in a thermostat at a temperature of 37°C. After this the mixture was boiled during 10 minutes and passed through a paper filter. The filtrate was neutralized with sodium bicarbonate and filtered again. The liquid portion was dialysed through the films of collodium bags during 36—48 hours, after which it was centrifugated. The transparent liquid was found to contain ribonuclease.

Dry smears of *Paramoecium* cultures were fixed with 96° alcohol. The *Paramoecia* so fixed were, moreover, embedded in paraffin, and sections prepared of them. The preparations were placed for 90 minutes into a solution of ribonuclease at a temperature of 58—65°. The control smears and sections were kept during an equal

period at a similar temperature in distilled water. Part of the preparations were subjected to no preliminary treatment. The *Paramoecia* were stained with methyl-green-pyronine after Unna. Brachet points out that pyronine seems specifically to stain in the cells their basophilic elements which contain zymonucleic acid. Aside from Unna's method, we applied also staining after Dominici and Giemsa, staining the control preparations and those treated with ribonuclease, respectively.

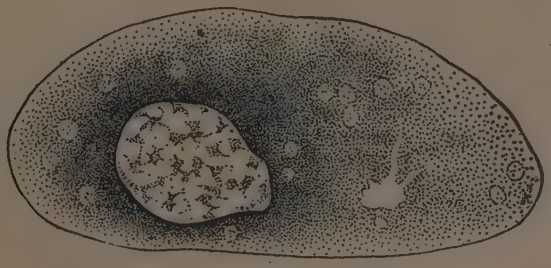

Fig. 2

The examination of the smears stained with methyl-green-pyronine revealed the following picture. On those preparations which underwent no preliminary treatment (Fig. 1) the whole of the endoplasm of the *Paramoecia* stains intense red. The ectoplasm assumes a pale-blue tint. Under high magnifications one may detect in the endoplasm, along with areas with a homogeneous red plasm, also threads and grains of various shape which stain with pyronine. After the smears are treated with hot distilled water (Figs. 2, 3) the endoplasm is stained with pyronine less

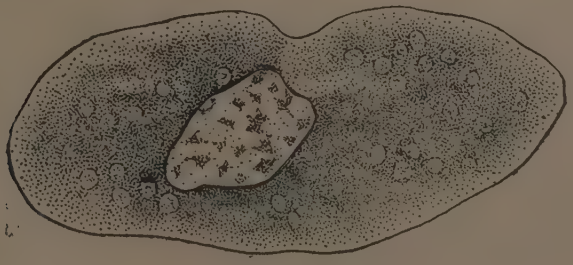

Fig. 3

intensely. A treatment with ribonuclease (Fig. 4) leads to a total disappearance of the «pyroninophilic» substance: nothing besides a pale-blue spongy plasm may be seen on the preparation. Thus, we find in the plasm of *Paramoecia* two pyroninophilic components, the one of which dissolves when treated with hot distilled water, while the other is eliminated when acted upon with ribonuclease. Taking into account the specific action of the ribonuclease, it may be assumed that the second component is nothing else than cytoplasmic nucleic acid.

By comparing different preparations it becomes evident that the zymonucleic acid occurs in the cytoplasm of *Paramoecia* in various amounts and is differently distributed there. Along with *Paramoecia* in which it is distributed regularly all over the plasm (Fig. 3), there are also such in which the pyroninophilic substance is concentrated only in the posterior part of the infusorium, or else, is tightly encircling the nucleus (Fig. 2). In others it is found in the posterior part of the body in the form of separate, lightly stained bands and grains. In some of the infusoria the pyroninophilic substance is seen diffusely to permeate the plasm, in others again fine-grained structures, either isolated or forming small cluts, are pre-

valent. Not infrequently a picture of mixed distribution of the pyroninophilic substance throughout the body of the infusoria may be observed.

In cross-sections made with the *Paramoecia* some details in the distribution of zymonucleic acid could be detected. While in some of the *Paraemocia* the basophilic substance is regularly distributed all over the plasm, in others a relatively broad superficial layer is deprived of the basophilic substance; lastly, such *Paramoecia* are also met with in which only separate areas of the plasm contain zymonucleic acid.

All these observations give ground to assume that the amount and distribution of zymonucleic acid in *Paramoecia* obeys a dynamical regularity of its own, and may be helpful in disclosing the factors that underly the variations referred to above.

The pyroninophilic substance is contained not only in the cytoplasm of *Paramoecia*, but in their macronucleus as well. The bulk of the nuclear substance stains blue with methyl-green, but there are pyroninophilic areas which constitute nothing else than the so-called «nucleoli of the macronucleus». These structures do

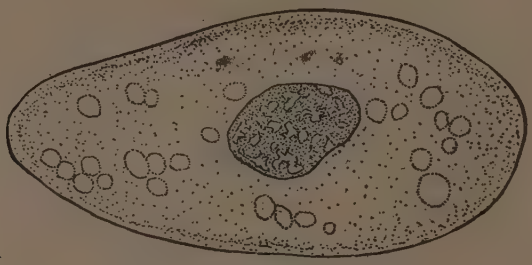

Fig. 4

not change when the material is treated with hot distilled water, but disappear altogether under the effect of ribonuclease (Fig. 4); at the respective spots in the macronucleus only vacuoles are left behind which do not stain with pyronine.

The micronucleus remains unchanged upon treatment with nuclease; it contains evidently no zymonucleic acid.

Our data should be taken to mean that the basophily of the plasm of *Paramoecia* is largely due to the presence of cytoplasmic nucleic acid. We cannot, however, consider the presence of this acid as the unique cause of the plasm being basophilic. It has already been pointed out that in the case of treatment with hot distilled water, there takes place dissolving and elution of some basophilic substances, the nature of which still defies determination.

Aside from the observations here described, we have also studied some smears stained after Dominici and Giemsa. When the latter procedure was applied to smears subjected to no preliminary treatment, the plasm of the infusoria stained blue (the intensity of the colour varying as to the specimen). Upon treatment with distilled water the intensity of the colour decreases, and in most of the *Paramoecia* the plasm displays different shades of light-blue. The plasm of infusoria treated with ribonuclease stains a delicate red-violet which may readily be distinguished from the colour taken on by the plasm of the *Paramoecia* in the control preparations.

When stained according to Dominici the basophiic substance was not revealed after a treatment with ribonuclease, or else, it was but very slightly expressed: the blue or deep-violet plasm of those infusoria that underwent no preliminary treatment, or were treated with water, can easily be distinguished from the light red-violet plasm of the *Paramoecia* that have been treated with ribonuclease.

All these observations carried out on the macro- and micronucleus on preparations stained according to Unna have been fully confirmed in the case of Giemsa's and Dominici's methods as well.

Hence we are justified to draw the following conclusions:

1. The following two components are responsible for the basophilic nature of the plasm of *Paramoecia*: the one is soluble in hot distilled water, the other in ribonuclease, being a substance either identical with, or closely related to zymonucleic acid.

2. The mode of distribution and amount of zymonucleic acid varies as to individual *Paramoecia*. One is therefore authorized to speak of a dynamic of the zymonucleic acid in infusoria at different moments of their life-cycle.

3. The nucleoli of the macronucleus in *Paramoecia* consist of zymonucleic acid or, at least, contain a considerable amount of it.

4. The micronucleus contains no zymonucleic acid.

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*GENETICS*

# PRODUCTION OF AMPHIDIPLOIDS OF *TRITICUM ORIENTALE* × × *TRITICUM TIMOPHEEVI* BY COLCHICINE TREATMENT

By A. R. ZHEBRAK, Member of the Academy of Sciences of the White Russian SSR

In order to obtain amphidiploids of *Triticum Timopheevi* with the greatest possible number of various types of wheats, *T. orientale* which had been classified by Percival as a separate species, was also included in hybridization with *T. Timopheevi*. K. A. Flaxberger considers that there are no grounds for classifying *T. orientale* as a separate species and he refers this type of wheat to *T. durum* (1).

Amphidiploid ear of *T. orientale* × *T. Timopheevi*

As our object was to obtain amphidiploids of *T. Timopheevi* with various types of wheat, this type was, of course, of great value for our purpose.

*T. orientale* is characterized by low adaptability to surrounding conditions and has a limited area (Turkey, Iran, Mesopotamia). This type of wheat is more susceptible to rust and to mildew than any other hard wheat. The kernel of *T. orientale* is long, glassy and resembles that of *T. polonicum*.

According to the characters of its ears, this wheat species occupies an intermediate position between *T. polonicum* and *T. durum*.

For crossing it with *T. Timopheevi* we selected the variety *insigne*, referred to in the VIR catalogue as No. 15992. This variety has a long ear with long pubescent scales (glumae) of the spikelets. In the summer 1939 204 flowers of *T. orientale*, v. *insigne*, were pollinated by pollen of *T. Timopheevi*, and a total of 7 hybrid kernels were obtained, which makes 3.4 per cent fruit-setting out of the total number of pollinated flowers. All the kernels were well developed and differed but slightly from those of the mother plant, *T. orientale*.

In the spring 1940 all the 7 kernels were germinated and the young seedlings were dipped for 48 hrs into a 0.025 per cent colchicine solution. Upon the treatment the young plants were washed with water and planted into clay pots.

After the plants had developed they were transplanted into the field with the exception of one plant which remained in the pot throughout the whole growing period.

Out of the total of 7 germinated seeds 6 plants survived colchicine treatment and out of these 5 had amphidiploid ears. The mode of occurrence of these amphi-

diploid ears was not different from that of other hybrid combinations, in so far as there were completely sterile as well as completely fertile ears on the same plant. The fertility of amphidiploid ears was rather high. The ear represented on the figure had a total of 12 spikelets out of which there were 11 fertile ones, and these 11 productive spikelets had 25 amphidiploid kernels. The picture shows separate spikelets containing 3 kernels each.

Data on all the 6 experimental plants are summarized in the table.

| Combination and number of exp. | Number of plants | Number of entirely amphidipl. plants | Number of plants with amphidipl. ears | Total number of ears | Number of amphidipl. ears | Number of kernels in amphidipl. ears | Number of entirely sterile ears | Number of ears with a few kernels | Number of kernels in such ears |
|---|---|---|---|---|---|---|---|---|---|
| *T. orientale* × *T. Timopheevi*, 82 . . . . . | 6 | 1 | 5 | 44 | 9 | 153 | 32 | 3 | 5 |

Amphidiploid as well as non-amphidiploid ears of *T. orientale* × *T. Timopheevi* were shorter than those of *T. orientale* and longer than those of *T. Timopheevi*.

The leaves, stem and scales (glumae) of the spikelets were pubescent. The pubescence of the scales (glumae) of the spikelet was particularly developed. The amphidiploid kernels were long and rather well filled. The average length of the kernel was 11—12 mm, its width 4 mm, its height 4 mm. The embryo was one quarter of length of the back side of the kernel.

The weight of the kernels was found upon weighing all kernels of two amphidiploid ears (a total of 30 kernels, 25 + 5); these weighed 3.37 g which would make 79 g per 1000 kernels.

In our experiments of 1942 the weight of 1000 kernels appeared to be considerably higher; the mean value (all the kernels of many ears were weighed) attained 95.8 g. Fertility was 33 kernels per ear and 2.3 kernels per spikelet.

The number of chromosomes was determined in two plants grown from the kernels of amphidiploid ears. This proved to be 56, *i. e.* the total of the diploid sets of both initial parental species.

We thus have proved the fact that a new 56-chromosome amphidiploid type of wheat has been obtained.

Another very interesting fact has also been disclosed in this work and this, from our standpoint, will be of assistance in settling the question as to whether *T. orientale* should be considered a separate species, or a mere variety of *T. durum*.

We observed a considerable development of mildew (*Erysiphe graminis*) on the glumae of the spikelets of the amphidiploid ear and leaves; this had never occurred with any of our interspecific hybrids with *T. Timopheevi*. Consequently, from the physiological standpoint *T. orientale* differs considerably from the rest of hard wheat species.

If taxonomy of wheats was based not only upon morphological characters, but on physiological and ecological properties as well, *T. orientale* should be more properly classified as a separate species.

The type of ears in amphidiploid *T. orientale* × *T. Timopheevi* is markedly different from that in the amphidiploid *T. durum* × *T. Timopheevi*.

Until we had obtained amphidiploids of *T. orientale* × *T. Timopheevi* and had investigated their characteristical peculiarities we were inclined to join Flaxberger in considering *T. orientale* as a variety of *T. durum*. But now, after we have found great morphological and physiological difference between the amphidiploids of *T. orientale* × *T. Timopheevi* and the amphidiploids of *T. durum* × *T. Timopheevi*, we come to the conclusion that *T. orientale* should more correctly be considered a separate species of wheat, the difference in the amphidiploids resulting from the

very pronounced specific properties of *T. orientale*, on account of which this type of wheat may be classed as a separate species.

The amphidiploid of *T. orientale* × *T. Timopheevi* obtained is referred by us to the subspecies *T. soveticum* ([2],[3]).

In the experimental part of this work I was assisted by the following members of the Department of Genetics of the Timiriazev Agricultural Academy: A. S. Aphanassieva, A. D. Belova, P. T. Skotnikova and M. G. Tom, to whom I wish to express my gratitude.

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*PLANT PHYSIOLOGY*

# CARBOHYDRATES AS AN INDEX IN DETERMINING WINTER HARDINESS OF RED CLOVERS OUTSIDE THE POLAR CIRCLE

By S. A. KASPAROVA and T. A. PROSKURNIKOVA

*(Communicated by L. A. Orbeli, Member of the Academy, 14.VII.1943)*

In perennial *Leguminosae* winter hardiness, as well as the obtaining of stable yields is limited under the conditions prevailing outside the Polar circle by a whole complex of perennial factors. The most essential of them are the intensity of development of *Leguminosae* at the period of growth, the degree to which they are ready to hibernation, the store of plastic substances, the intensity of their consumption and, lastly, the physiological condition of the wintering organs at the period of rest.

On account of the very short vegetation period, the continuous polar day, frequent interchange of spring-summer and autumnal temperatures and the long period which the plant passes under snow-cover, all these factors are subject to continous variation.

Our experimental work was carried on under field conditions; as material the red clover *Trifolium pratense* (in its perennial reproduction by Eichfeld-Povir) was made use of. The plants were grown in field at a continuous arctic day.

Among red clovers such representatives have been chosen as show different winter hardiness when grown in the North: Pechorsky (winter-hardy), Molstadt (less winter-hardy), Belozerkovsky (not winter-hardy). The behaviour of the plants was watched from the beginning of the period of growth till the end of their wintering in the soil.

To determine the state of the plants and investigate the biochemical processes that take place in wintering plants, sampling was done in October, March and May. The thickness of the snow-covering at the experimental plots attained 1.5 m and kept to this level throughout the period of sampling. The average test-samples composed after digging were tested for carbohydrates and enzymes.

The kind of the carbohydrates was determined according to Kiesel's scheme [10], the following modifications being introduced: sugars were extracted with water, the maltose fraction was determined along with dextrines, and starch along with hemicelluloses.

Course of Development of Clover Plants. Representatives of different varieties of the red clover sown at the same time differ as to the intensity of growth, which may be seen from Table 1, showing the course of accumulation of dry mass. Thus, variety Molstadt and the semi-wild clover Pechorsky display a lower rate of growth as compared to the variety Belozerkovsky.

Of interest are also the rates of the development of different clover varieties. While Molstadt and Pechorsky towards the period of growth attain merely the stage of the rosette, forming a considerable number of wintering buds, the Belozerkovsky

Table 1

Course of Accumulation of Dry Mass by Clovers (10 plants)

| Harvested on | Molstadt | | | Belozerkovsky | | | Pechorsky | | |
|---|---|---|---|---|---|---|---|---|---|
| | Weight | | | Weight | | | Weigth | | |
| | total | roots | leaves | total | roots | leaves | total | roots | leaves |
| July . . . | 4.7 | 1.8 | 2.9 | 6.4 | 2.9 | 3.5 | 3.7 | 1.5 | 2.2 |
| August . . | 16.7 | 6.3 | 10.4 | 21.3 | 9.5 | 11.8 | 11.2 | 4.9 | 6.3 |
| September . | 147.3 | 52.5 | 94.8 | 259.2 | 126.9 | 132.3 | 150.6 | 84.0 | 66.3 |
| October . . | 324.3 | 117.1 | 207.2 | 368.5 | 142.0 | 226.5 | 303.1 | 166.4 | 136.7 |

variety often reaches the stage of flowering during its first year, and occasionally even that of fruiting, the number of wintering buds being small and the development of the root system a poor one.

The representatives of those clovers in which the development proceeds after the type of the Pechorsky and Molstadt varieties pass into wintering without suffering any appreciable injury, under supply of plastic substances, and withstand wintering fairly well. Unlike this, clovers whose development follows the type of. the Belozerkovsky variety, do often perish before wintering or during the winters

Carbohydrates and Their Conversion in Clovers during the Period of Growth and Passing to Wintering. The results of the physiological conversion of the carbohydrates at various periods of development of clovers are given in Table 2.

As may be seen from the figures of Table 2, by the moment of vigorous development of the rosette and sprouts (early in September) the fraction of monosugars is prevalent in the leaves of all varieties over other groups of soluble carbohydrates. The roots present a different picture: here the main part of sugars belongs to the carbohydrates of the type of maltose which are not readily hydrolysed.

The greatest accumulation of soluble carbohydrates and of their separate fractions, as well as of total carbohydrates takes place in the leaves and roots of the not winter-hardy variety, Belozerkovsky; next follows Pechorsky, whereas the last place is occupied by Molstadt. At this period the ratio monosugars : sucrose, as well as the ratio maltose : sucrose are above unity everywhere.

The intense accumulation of carbohydrates by the Belozerkovsky clover is accounted for by its ripening, i. e. by biological state different from that of the other two types. When the plants make themselves ready to hibernation (October), the carbohydrate metabolism assumes a somewhat different character, as may be seen from Table 2. The ratio monosugars: sucrose decreases, and that maltose : sucrose even drops below unity.

The variation of the content of the maltose fraction with the age of the leaves of clover is of particular interest, since in other cultures it has only been observed in old leaves if at all. According as the leaves grow older, the sugars start migrating to the roots, and their quantity in the leaves decreases accordingly.

The Pechorsky variety which is more winter-hardy shows a tendency towards a greater accumulation of sugars and of total carbohydrates in its roots. In the Belozerkovsky variety the content of carbohydrates drops by this time, which is probably connected with the complicated process of the formation of reproductive organs. Unlike the other two varieties, Belozerkovsky achieves by the end of October its developmental cycle by passing through the phase of flowering and fruit-bearing. The trend of the carbohydrate metabolism in clovers is determined by the activity of enzymes, which may be seen in Table 3.

The migration of sugars from the leaves into the root is determined by the relation between the synthetic and the hydrolytic activity of the invertase, which has been demonstrated in earlier studies [1–3].

The clovers of the northern type, Molstadt and Pechorsky, do not display such a sharp difference between the hydrolytic activity of invertase in their roots and

Table 2

Carbohydrate Metabolism at Various Periods of Development of Clovers
(in % to abs. dry weight)

| Plants | Leaves | | | | | | Roots | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mono-sugars | Sucrose | Monosugars / sucrose | Maltose | Total sugars | Total carbohydrate | Monosugars | Sucrose | Maltose | Total sugars | Total carbohydrate |
| September 3 | | | | | | | | | | | |
| Molstadt | 4.8 | 1.26 | 3.3 | 2.91 | 8.97 | 16.29 | 0.07 | 3.20 | 8.63 | 11.90 | 42.21 |
| Pechorsky | 9.91 | 2.90 | 3.4 | 7.28 | 20.09 | 26.45 | 0.0 | 7.20 | 18.45 | 25.65 | 42.51 |
| Belozerkovsky | 14.95 | 2.19 | 6.8 | 10.09 | 27.24 | 28.57 | 0.0 | 11.33 | 37.65 | 48.98 | 58.15 |
| October 23 | | | | | | | | | | | |
| Molstadt | 6.27 | 6.16 | 1.0 | 3.74 | 16.17 | 24.71 | 0.0 | 9.50 | 23.16 | 32.66 | 53.20 |
| Pechorsky | 6.27 | 5.41 | 1.2 | 2.33 | 14.01 | 25.28 | 0.0 | 14.14 | 32.63 | 46.77 | 57.76 |
| Belozerkovsky | 6.56 | 4.29 | 1.6 | 3.31 | 14.16 | 24.18 | 0.0 | 8.5 | 26.38 | 34.88 | 50.94 |

Table 3

Activity of Enzymes and Content of Carbohydrates in Clovers
Previous to their Passing to Wintering

| Variety | Leaves | | | | | | | Roots | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mono-sugars | Sucrose | Maltose | Starch | Inver-tase | Amylase | Peroxi-dase | Mono-sugars | Sucrose | Maltose | Starch | Inver-tase | Amylase | Peroxi-dase |
| Molstadt | 6.27 | 6.16 | 3.74 | 8.58 | 6.39 | 40.95 | 14.40 | 0.0 | 9.53 | 8.63 | 20.54 | 3.46 | 48.69 | 38.17 |
| Pechorsky | 6.27 | 5.41 | 2.33 | 11.27 | 6.53 | 42.39 | 17.74 | 0.0 | 14.13 | 18.45 | 10.99 | 2.74 | 36.09 | 40.86 |
| Belozerkovsky | 6.56 | 4.29 | 3.31 | 9.72 | 14.53 | 50.13 | 26.71 | 0.0 | 8.5 | 37.15 | 16.06 | 5.60 | 35.19 | 46.73 |

leaves as that shown by the Belozerkovsky clover, a variety which has been later introduced from the South to the North. Because of the increased invertase activity the amount of saccharose in the latter variety is considerably lower than in the two former. Hence it may be assumed that introduced *Leguminosae* can well develop beyond the Arctic circle and be winter-hardy provided they will possess a high synthesizing ability during the spring-summer period, and store a large amount of plastic substances before they pass to hibernation, remaining at the same time in a state of young stage.

The antagonism between the activity of the hydrolases and oxidases of the aboveground and the underground organs and the dependence of the increased synthesis on the intensity of oxidation processes is confirmed in this case, as well ([4,5]).

Owing to the high synthesizing ability of their cells, the roots are also rich in saccharose. Such a relation in the enzymic activities going on in the roots is favourable for their readiness to wintering.

In the carbohydrate metabolism an essential part is played by the amylase, too. Both leaves and roots are found to display irrespective of the variety, before wintering, a similar hydrolytic activity of amylase, while these organs contain different amounts of the separate fractions of water-soluble carbohydrates.

As determination of the activity of this enzyme is essentially dependent on the kind of carbohydrates ([6]), it should be supposed that the hydrolytic activity of the amylase being similar in aboveground and underground organ, its synthetic activity is likely to be differently expressed in them: as has already been pointed out, the transition of monoses into bioses in roots increases the synthetic activity of amylase and contributes to a better synthesis of starch.

Carbohydrates and their Transformations during the Wintering of Clovers. After the nature of the biochemical processes which go on during the winter it is possible to form an idea as to the physiological state of the different clover varieties and the duration of their resting period, which characterize the degree of their winter-hardiness (Table 4).

Table 4

Variation in the Carbohydrate Content in Roots of Clovers Wintering in the Ground (in % to abs. dry weight)

| Clover variety | Monosugars | Sucrose | Maltose | Total sugars | Starch | Total carbohydrate | Number of roots in % to average sample | | Number of sprouted roots |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Living | Dead | |
| October 23 | | | | | | | | | |
| Molstadt | 0.0 | 9.50 | 23.16 | 32.66 | 20.54 | 53.20 | All healthy | No | No |
| Pechorsky | 0.0 | 14.14 | 32.63 | 46.77 | 10.99 | 57.76 | | | |
| Belozerkovsky | 0.0 | 8.5 | 26.38 | 34.88 | 16.06 | 50.94 | | | |
| March 7 | | | | | | | | | |
| Molstadt | 1.91 | 8.74 | 6.84 | 17.49 | 13.47 | 30.96 | 99.75 | 0.25 | Single |
| Pechorsky | 0.65 | 12.34 | 14.84 | 27.85 | 16.69 | 44.54 | 100.0 | 0.0 | |
| Belozerkovsky | 0.18 | 8.29 | 2.27 | 10.74 | 12.95 | 23.69 | 82.0 | 18.0 | |
| May 23 | | | | | | | | | |
| Molstadt | 2.79 | 2.43 | 5.15 | 10.79 | 9.08 | 19.45 | 86.7 | 13.3 | In mass |
| Pechorsky | 0.0 | 12.95 | 26.15 | 39.10 | 8.96 | 48.06 | 99.4 | 1.6 | |
| Belozerkovsky | 0.55 | 1.10 | 3.73 | 5.39 | 10.71 | 16.10 | 69.20 | 30.80 | |

Because of the profound hydrolytic processes taking place during the period of stable rest (October, March) the content of monosugars does partly increase, while the content of saccharose undergoes but slight variations. At this period we observe a definite physiological periodicity both in the migration and consumption of carbohydrates. The decrease of the total sugars takes place largely at the expense of maltose.

The other fractions of soluble carbohydrates are not liable to such considerable variations; this circumstance makes us assume that at the resting period the principal part in the carbohydrate metabolism of clovers is played by sparingly soluble carbohydrates of the type of maltose which is the chief reserve polysaccharide. As soon as the period of rest is disturbed and the processes of growth activized (clovers start growing when still under snow), starch becomes also involved in carbohydrate metabolism, after preliminary hydrolysis.

The winter-hardy variety Pechorsky spends less carbohydrates than the two other varieties. Being poor in carbohydrates, the wintering organs and developing buds are liable to carbohydrate starvation, which reduces their vital tonicity and their existence at the period of the long winter rest ([7],[8]). Besides, plants that remain towards the spring with smaller reserves of energy (for example, the Belozerkovsky variety) are more subject to the influence of low spring temperatures([9]).

The physiological properties of the wintering organs at the period of hibernation, and the subsequent variations that proceed in them, are intimately connected with enzymic activity (Table 5).

The hydrolytic activity of invertase and amylase at the period of wintering is displaced in all clover varieties, and the more winter-hardy the variety, the more pronounced is the shift towards hydrolysis.

In the case of disturbance of the period of rest or that of germination, the activity of the hydrolytic enzymes is suppressed again, while that of the oxidizing increases.

Table 5

Variations in the Enzymic Activity of Clover Roots during Hibernation (activity of peroxidase in 0.1 *N* $KMnO_4$ per 1 g raw weight, of invertase and amylase in mg of various sugars per 1 g raw weight)

| Clover variety | October 23 | | | March 7 | | | May 23 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Invertase | Amylase | Peroxidase | Invertase | Amylase | Peroxidase | Invertase | Amylase | Peroxidase |
| Molstadt | 3.46 | 48.69 | 38.17 | 19.95 | 50.85 | 37.95 | 7.92 | 51.75 | 51.36 |
| Pechorsky | 2.74 | 36.09 | 40.86 | 24.12 | 52.20 | 48.80 | 12.6 | 49.44 | 49.90 |
| Belozerkovsky | 5.60 | 35.19 | 46.73 | 3.96 | 42.12 | 28.46 | 10.96 | 32.29 | 42.90 |

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# DEVELOPMENT OF TAU-SAGHYZ SEEDLINGS AS AFFECTED BY ORGANIC ACIDS

By W. E. PONTOVICH

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Organic acids are known to play an important rôle in the cell metabolism of both lower and higher plants. Such phenomena are known, for example, as the diurnal periodicity in the accumulation of oxalic and malic acid in *Crassulaceae* (1), formation and accumulation of a number of organic acids by smut fungi (2), elimination of organic acids by the root systems of plants (3). We are also acquainted with the part played by various acids (the succinic, fumaric, malic, citric, aspartic, glutamic and others) in the synthetic processes taking place in the cell (4—9).

Being highly susceptible to the acidity of the medium, tau-saghyz offers a most interesting material for investigating the influence of organic acids upon the development of plants. And this is the more so as, owing to the properties of the soil and of the root system, the conditions under which tau-saghyz is cultivated are often propicious to the formation of organic acids in the rhizosphere, which is often fatal for this crop*.

It seems of interest to find out whether it is the acidity of the medium (low pH) which is fatal for the plant, or the chemical nature and the structure of the organic acids (*i. e.* the plant is affected by the anions of the acids proper).

The data here reported have been derived from numerous qualitative tests whose accuracy makes them fully comparable. In all of them the method of sterile cultures(10) was applied. This method is particularly convenient for our purpose since, entirely eliminating the influence of microbe on the development of the plant, it permits directly to watch the development of the root; moreover, it makes it possible to grow within a short period of time a large number of cultures without any green- or glasshouse.

We at first tested various nutrient media with the aim to select the form of mineral nitrogen that would suit tau-saghyz and also to create an optimal value of pH.

Values of pH optimal for the development of tau-saghyz range between 7.0—7.6; with a pH =6.5 the roots begin to suffer, and with a pH $\leqslant$ 6.0 they become brown and die off.

Three liquid mineral synthetic media were tested; their composition was as follows:

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* The soils at the tau-saghyz plantations in South Kazakhstan *e. g.* are heavy, structureless, pelituous, liable to silting and to crust formation.

**Medium 1**

$(NH_4)_2SO_4$ . . . . . 0.1 g
$MgSO_4$ . . . . . 0.025 »
$KH_2PO_4$ . . . . . 0.025 »
$Fe_2(SO_4)_3$ . . . . . 0.001 »
Aq. dest . . . . . 100 cm³

$CaCO_3$ is sterilized separately and introduced upon sterilization.

**Medium 2**

a) $Ca(NO_3)_2$ . . . . . 0.1 g
$KNO_3$ . . . . . 0.025 »
$MgSO_4$ . . . . . 0.025 »
$Fe_2(SO_4)_3$ . . . . . 0.001 »
Aq. dest. . . . . 100 cm³
b) Mixture
$KH_2PO_4+K_2HPO_4$
($^1/_3$ mol) 1 : 3 . . . . 0.025 g

The mixture of phosphates is sterilized separately and added upon sterilization.

**Medium 3**

$NH_4NO_3$ . . . . . 0.1 g
$MgSO_4$ . . . . . 0.025 »
$Fe_2(SO_4)_3$ . . . . . 0.025 »
$KH_2PO_4+K_2HPO_4$
($^1/_3$ mol) 1 : 3 . . . . 0.025 »
Aq. dest. . . . . 100 cm³

The initial magnitudes of these three media are, respectively, 7.6, 7.1 (7.2 upon sterilization), and 7.1 (7.2 upon sterilization).

The cultures were grown in test-tubes with a 30 cm³ capacity, made to contain 20 cm³ of the respective medium each. The seeds were sterilized and the seedlings planted after the method earlier described ([10]). The results are summarized in Table 1.

Table 1

Development of Tau-saghyz Seedlings in Media with Different Sources of Mineral Nitrogen

| Nutrient media | pH | | Age of seedlings in days | Length of root, cm | Mode of growth |
|---|---|---|---|---|---|
| | prior to test | after test | | | |
| Medium 1 . . . . . | 7.6 | 7.2 | 14 | 2.5 | Aboveground part developed almost normally, root fails to grow |
| Medium 2 . . . . . | 7.10 | 6.42 | 32 | 19.5 | Plant well developed, 2nd pair of leaves well developed |
| Medium 3 . . . . . | 7.48 | 5.5 | 32 | 15 | One well developed leaf, root thin. By the end of test the plant began to perish |

From the table it may be seen that although the initial magnitudes of the pH are optimal in all the three media (7.1—7.6), the development of the plants grown on them assumes a different course: the less favourable is the medium in which as a source of nitrogen ammonia is made use of (medium 1), while the most favourable is that with nitrates as a nitrogen source (medium 2).

This is in good agreement with data by Tanaka ([11]) who showed that the effect of all the ammonia salts, except for $NH_4NO_3$, upon the growth of plants is no beneficial one, even if glucose is available.

From the table it is also evident that in the process of their development the roots of tau-saghyz do rather considerably oxidize the nutrient medium; the oxidizing effect is especially well pronounced with medium 3 (pH = 5.5).

This should be taken to mean that in spite of their negative reaction to the nitrogen when introduced in the form of ammonia, the roots of tau-saghyz absorb in this case in the first line ions of $NH_4$, thus liberating nitric acid* ([12]).

On account of the data secured, for our subsequent tests with organic acids we took medium 2 (somewhat modified Knop-solution), as being the most favourable for the development of tau-saghyz.

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* This phenomenon was observed by number of writers, both in micro-organisms and higher plants.

The following acids were subjected to investigation: citric acid, quinic acid, lactic acid, glyceric acid, glycolic acid, β-oxy-butyric acid, succinic acid, malic acid, pyruvic acid, valeric acid, propionic acid, tartaric acid and aspartic acid.

By neutralizing these acids with weak solutions of potassium or ammonia, the pH of the media was brought up to 7.4—7.6. The cultures were kept in light, without glucose or with addition of 2 per cent of glucose. Part of the data obtained are summarized in Table 2.

Table 2

Development of Tau-saghyz Seedlings in the Presence of Potassium Salts of Organic Acids

| Acids | Concentration mol/l | Weight of plant (air-dry weight) in mg | |
|---|---|---|---|
| | | without glucose | with glucose |
| Quinic | 0.05 | 23.0 | — |
| Citric | 0.002 | 23.0 | 17.0 |
| Lactic | » | 20.0 | 24.0* |
| Succinic | » | 18.0 | — |
| Pyruvic | » | 15.0 | 11.0 |
| Valeric | » | 11.0 | 12.5 |
| Malic | » | 10.0 | 23.5* |
| Propionic | 0.004 | 9.5 | 15.5 |
| Control | No acid | 13.0 | 19.0 |

* In these cases the plants develop on ammonia salts, but the rate of their development did not differ from that of plants given potassium salts.

The concentrations of the acids taken at the beginning of our tests (0.01 mol/l) proved too high. For example, when malic or aspartic acids were used at such concentrations, the roots of tau-saghyz got rapidly brown and perished in spite of a pH of the medium that was optimal for their development. The most favourable proved the concentrations ranging between 0.002 and 0.004 mol/l for all acids, except citric acid which gave the best results when present in the medium at a concentration of 0.05 mol/l.

As may be seen from the experimental data summarized in Table 2, in spite of the identical initial pH of the cultures (7.0—7.3 upon sterilization) the tau-saghyz plants developed differently with all the acids tested: in some of the cases (for example, with malic, valeric, propionic, tartaric and aspartic acids) the experimental plants were behind the controls. With the rest of acids, they compared favourably with the controls, but individual plants differed from one another, their weight ranging from 15 to 23 mg.

Thus, the growth and development of tau-saghyz is affected not only by the acidity of the medium, but also by the anions of the respective acids proper, *i.e.* by the nature and the chemical structure of the acids.

The data secured give us ground to believe that monobasic acids, especially short-chain ones, suppress the development of the seedlings (for example, propionic and valeric acid); whereas monobasic acids with the carbonyl group, or especially the oxy-group, are favourable for their development (for example, lactic or pyruvic acid).

With dibasic acids, especially succinic acid, the seedlings show a good growth, but according as the number of oxy-groups and the dissociation constant of the acids increase, the development of the plants is depressed. For instance, with malic acid there is already observed a poorer development than with citric acid, while tartaric acid has a strongly suppressing effect upon the development of the plants.

This phenomenon can in some way be explained by the magnitudes of the pH of the media by the end of the tests. The fact is that according as the seedlings develop in the presence of acids, the media are found to be alkalized without glucose. Thus we have:

| Acid | pH previous to test | pH after test |
|---|---|---|
| Quinic | 6.80 | 7.84 |
| Citric | 7.38 | 7.90 |
| Lactic | 7.02 | 7.70 |
| Succinic | 7.04 | 7.30 |
| Pyruvic | 6.90 | 7.78 |
| Malic | 7.00 | 7.62 |
| Propionic | 7.30 | 7.69 *etc.* |

This alkalization points to the fact that the root absorbs more intensely the anions than the cations of the acid. Besides, pH measurements have shown that the better the growth, the more alkalized is the medium.

If the seedlings develop on ammonia salts of organic acids, the relations observed are somewhat different from those given in Table 2.

In this case there is rather poor growth with citric, quinic, β-oxy-butyric and glycolic acids, and good development with propionic and succinic acids. This may evidently be accounted for by different conditions of absorption of ammonia salts, and the more so as in those cases by the end of the tests we often observed acidulation rather than alkalization of the media (without glucose). Thus:

| Acid | pH prior to test | pH after test |
|---|---|---|
| Quinic | 7.40 | 6.89 |
| β-oxy-butyric | 7.07 | 6.98 |
| Pyruvic | 6.90 | 6.49 |
| Valeric | 6.90 | 6.70 |
| Propionic | 7.50 | 7.30 *etc.* |

From these measurements of the pH one may suppose that the absorption of $NH_4^+$ ions goes on more energetically than that of anions of the acids.

Even at a concentration of 0.002 mol/l in the form either of potassium or ammonia salt, aspartic acid is found to suppress the development of seedlings. This observation is in agreement with data reported by other writers for various plants ([11]).

It is of interest to note that, when organic acids are present in a medium together with glucose, the weight of the seedlings is mostly increased thereby. The presence of glucose without acids (in control cultures) also gives some increase in the weight of seedlings, though a very slight one, as compared with the data reported by other writers for other plants ([11]).

In order to find out whether tau-saghyz plants are actually more susceptible to the medium's acidity (low pH), especially to the anions of the acids, as compared to the rest of plants, we undertook sterile cultures of radish under similar conditions, except for an addition of malic acid at a concentration that would be fatal for tau-saghyz seedlings, *viz.* 0.01 mol/l. Under these conditions we observed a good development of the aboveground part of the radish plants (cotyledons and leaves), and an opulent development of the root-system, *i. e.* the appearance of numerous lateral roots; at the same time no thickening of the subcotyledonal part of the root could be observed.

Thus, in spite of the fact that some of the acids investigated by us are considered to be intermediate substances in the synthesis of aminoacids, the results obtained do not justify the conclusion that they are being used up as such by tau-saghyz plants. We rather have here the inverse phenomenon, *viz.* in number of cases the effect of the anions of organic acids upon the development of tau-saghyz is a negative one.

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*PHYTOPATHOLOGY*

# BACTERIAL LEAF SPOT OF OATS CAUSED IN THE USSR BY *BACTERIUM CORONAFACIENS* ELL.

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Among bacterial diseases of cereals it is the black bacteriosis of wheat that has been thoroughly investigated within the last years ([2]) in this country; and quite recently another bacterial disease of the same crop, caused by *Bacterium atrofaciens* MC (Galachyan).

Concerning bacterial diseases in other cereal, only fragmentary information is available, merely recording their occurrence in a certain region ([1]).

Especially wide is the distribution of the bacterial leaf spot of oats which is common up to the Cola peninsula ([3]). Until recently this disease was diagnosticated by its symptoms observable on leaves; in detail it was investigated during 1940 at the Voronezh station for plant protection. The work was carried on in 1941 at the Laboratory for bacterial diseases at the Moscow Station for Plant Protection. The results of this work have been briefly summed up in this note.

D e s c r i p t i o n o f t h e D i s e a s e. The symptoms of the disease may be observed soon after the appearance of sprouts. The young oat leaflets show at first watery spots; these dry up and become reddish in colour, leading ultimately to the dying away of the leaf blade. On the leaves of adult plants the disease is expressed in the form of large diffuse spots. They are angular in shape, stretched all along the leaf, frequently covering the whole area of the leaf blade. As a rule, the disease begins at the edge of the leaf. The spots are brown red, lighter in the centre.

A g e n t. Two micro-organisms have been described by Elliot ([5],[6]) in the USA as being responsible for a disease with similar symptoms. Those micro-organisms, *Bacterium coronafaciens* Ell. and *B. striafaciens* Ell., can be distinguished after the symptoms they produce, while they are scarcely identifiable by their morphological and cultural characters.

In 1940 Naydenko succeeded in isolating in the Voronezh district from affected oat leaves a bacterium that has been found pathogenic for this crop. Later on this micro-organism has also been isolated from samples collected at the various points of this Union and studied in detail at this Laboratory. They all proved similar as to their morphological and cultural characters. A comparison of the bacteria isolated with those known to cause the bacterial leaf spot in oats is given in the Table 1.

From the comparison it may be seen that the micro-organism isolated by us approaches most closely *B. coronafaciens* Elliot; it is to this species that we refer it.

T h e p a t h o g e n e i t y of the bacteria isolated for oats was demonstrated by the experiments carried out at Mitrofanovka (Voronezh district) in 1940, and

Characteristic of Bacteria Isolated from Oat Leaves in the USSR as Compared to the Agent of this Disease in the USA

Table 1

| Name of agent or place of isolation | Colour of colony | Broth | Mobility | Capsules | Spores | Staining after Gram | Morphology | $H_2S$ | Indol | Salpetre | Milk | | Starch hydrolysis | Gelatine | Fermentation of sugar | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | coagulation | peptonizability | | | glucose | galactose | lactose | saccharose |
| From diseaded oat leaves from Voronezh distr. | White, light-blue, transparent | Uniform turpidity, slight setting | + | + | — | — | Bacilli with curled tips | — | — | — | + | + | — | + | + | + | — | + |
| Same, from Moscow distr. . . . | Same | Same | + | + | — | — | Same | — | — | — | + | + | — | + | + | + | — | — |
| *Bact. coronafaciens* Ell. . . . | » | » | + | + | — | — | » | — | — | — | + | + | + (slight) | + | + | + | — | + |
| *B. striafaciens* Ell. . . . . | » | » | + | + | — | — | » | + | — | + (slight) | + | + | + | + | + | + | — | + |
| *B. atrofaciens* Ell. | » | » | + | + | — | — | » | + (slight) | + (slight) | — | — | + | + (moderate) | + | + | + | — | + |

in Moscow, 1941. The results of these experiments are summarized in Table 2. Inoculation was made by spraying previously injured leaves with a suspension of the bacteria.

Table 2

Results of Artificial Inoculation of Oat with *B. coronafaciens* Ell. (1940—1941)

| Place | Year | Season of inoculation | Season of manifestation | Incubation period in days | % of infected plants |
|---|---|---|---|---|---|
| Mitrofanovka, Voronezh distr. | 1940 | 24.V | 24.V | 2 | 100 |
| Moscow distr. | 1941 | 12.VI | 14.VI | 2 | 100 |
| Ermolino, Moscow distr. | 1941 | 26.VI | 29.VI | 3 | 100 |

The bacteria that have been isolated from the spots experimentally produced were tested for their pathogeneity again; a typical picture of the disease has been obtained in all cases.

Sources of Infection. Primary infection with *B. coronafaciens* is known to be transmitted by seeds and soil. Experiments carried on during 1940 showed that the ratio of contaminated sprouts grown from seeds collected from badly infected plots is no high one (about 2—3 per cent). This should be taken to mean that, although infected seeds may import the disease to the field, they do not necessarily constitute the main source of primary infection.

Work carried out in 1940 showed this to be transmitted by the remains of plants infected during the past season (Table 3).

Table 3

Part Played by Remains of the Crop in Contamination of the Oat Leitevizky with *B. coronafaciens* Ell. (Mitrofanovka, 1941)

| Location of the plot with respect to past season crop | Record made | % of plants contaminated |
|---|---|---|
| Near by (experimental field) | 24.V | 25.8 |
| At a distance of 250 m (same farm) | 24.V | 12.7 |
| Next to (collect. farm «Kr. Oktiabr») | 29.V | 34.8 |
| At a considerable distance from (same farm) | 29.V | 4.6 |

As shown by experiments, the most severely attacked by the bacteria are those leaves which have previously suffered some injury. Thus, under natural conditions the development of the disease proceeds in the following way: the first signs of the disease appear mainly on plants originating from contaminated seeds, or on a plot adjoining those planted with oats during the past season.

The bacteria are afterwards carried along by rain drops and wind and getting upon injured leaves contaminate them. Naturally enough, the disease is initially focussed around the primary foci; in the subsequent it becomes gradually distributed over the plot.

Specialization of the Bacteria Isolated. To find out whether and to what extent a given parasite is confined to a certain plant-host, is of interest from two standpoints: when choosing the elements of the crop rotation,

and when sorting out resistant varieties. As well known, varieties resistant to strictly specialized parasites are more easily sorted out.

In literature data are available as to the experimental infection with *B. coronafaciens* of wheat, barley and rye. Our results, however, failed to support these data (Table 4).

Table 4

Pathogeneity of *B. coronafaciens* Ell. for Grain Crops (Mitrofanovka, infected on June 7th, 1940)

| Bacteria isolated | Plant infected | Date of appearance of first symptoms | Definitive formation of spots | % of plants infected |
|---|---|---|---|---|
| Oat . . . . . | Barley | — | — | 0 |
| » . . . . . | Wheat | — | — | 0 |
| » . . . . . | Rye | — | — | 0 |
| » . . . . . | Oat | 10.VI | 11.VI | 100 |
| Control . . . . . | Oat | — | — | 0 |

As controls served leaves injured, but sprayed with water instead of bacterial suspension.

As may be seen, the bacteria isolated are highly pathogenic for oats, but do not infect wheat, rye or barley.

Thus, the present study does definitely bear out the bacterial nature of the brown spottiness of oat leaves, and identifies its agent.

The chief source of infection is found to lie mainly in the remains of the last season's crop and, to a smaller degree, in seeds. The agent is found to transmit the disease to oats, and not to do so to the rest of grains.

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